PRODUCT ENGINEERING

SEPTEMBER, 1952

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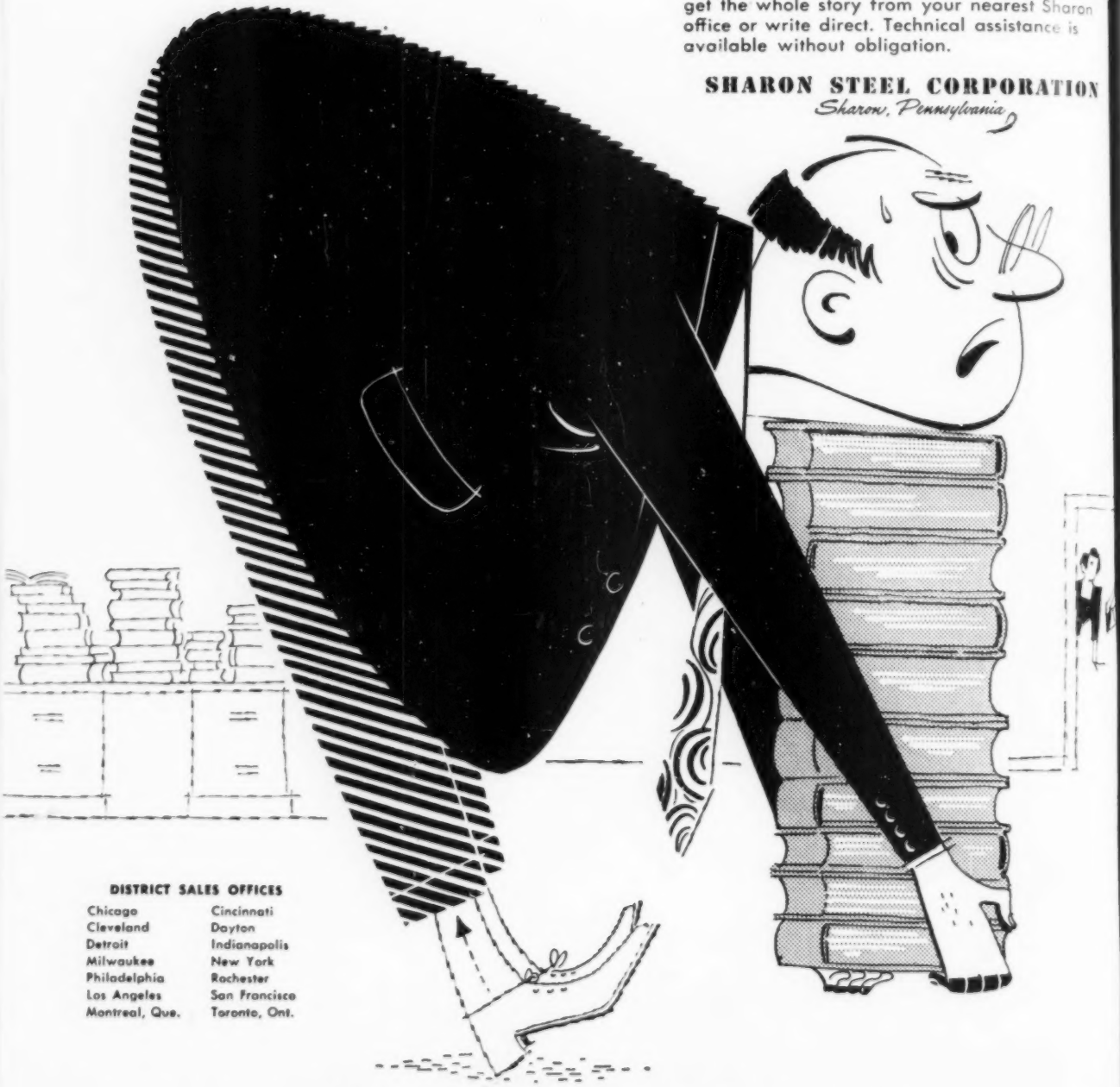
There's more to the Sharon 430 Stainless Steel Story than you might think!

Sharon '430' is not a newcomer to the stainless family — quite the reverse. It is the granddaddy of successful stainless types. It antedates the chromium-nickel stainless steels by many years, is a thoroughly tested steel with volumes of successful applications.

Automobile manufacturers have long used this material for complicated beading and trim where both the fabrication and end use have put it to critical tests. Hospital equipment, appliances, utensils, jewelry, hardware have all been made from Sharon '430' successfully. Absorption towers, used in the manufacture of nitric acid, built of '430' more than a quarter century ago, are still in everyday service.

Sharon '430' Stainless is available today with few restrictions as to end use. If you are in the market for a metal with above average quality, get the whole story from your nearest Sharon office or write direct. Technical assistance is available without obligation.

SHARON STEEL CORPORATION
Sharon, Pennsylvania



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Sharon 430 stainless steel

SHARONSTEEL

VOLUME 23 — PRODUCT ENGINEERING — NUMBER 9

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SEPTEMBER 1952

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Published monthly by McGraw-Hill Publishing Company, Inc., James H. McGraw (1860-1948), Founder. **Publication Office, 99-129 North Broadway, Albany 1, N. Y.**

Executive, Editorial and Advertising Offices: McGraw-Hill Building, 330 W. 42nd St., New York 36, N. Y. Curtis W. McGraw, President; Willard Chevalier, Executive Vice-President; Joseph A. Gerardi, Vice President and Treasurer; John J. Cooke, Secretary; Paul Montgomery, Senior Vice-President, Publications Division; Ralph B. Smith, Vice-President and Editorial Director; Nelson Bond, Vice-President and Director of Advertising; J. E. Blackburn, Jr., Vice-President, Circulation.

Subscriptions: Product Engineering—Subscription Service, 99-129 N. Broadway, Albany 1, N. Y., or 330 W. 42nd St., New York 36, N. Y. Allow one month for change of address.

Subscriptions are solicited only from executives, engineers and consultants engaged in the design of machinery and other engineered products.

Branch Offices: ATLANTA, H. M. Maultsby, 1321 Rhodes-Haverty Bldg.; BOSTON, M. A. Williamson, Jr., 350 Park Square Bldg.; CHICAGO, Anson E. Meanor, H. M. Higgins, 520 N. Michigan Ave.; CLEVELAND, A. F. Tischer, 1510 Hanna Bldg.; DALLAS, J. H. Cash, First National Bank Bldg.; DETROIT, P. G. Weatherby, 856 Penobscot Bldg.; LOS ANGELES, H. L. Keeler, 1111 Wilshire Blvd.; NEW YORK, J. A. McGraw and D. C. McGraw, Jr., 330 W. 42nd St.; PHILADELPHIA, David G. Jones, Architects Bldg.; PITTSBURGH, A. F. Tischer, 738-9 Oliver Bldg.; SAN FRANCISCO, R. E. Dorland, Jr., 68 Post St.; WASHINGTON, National Press Bldg.; LONDON, McGraw-Hill House, 95 Farrington St., London E.C. 4, England.

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Single copies 50¢. United States and possessions, $5 for one year, $8 for two years, $10 for three years; Canada, $6 for one year, $10 for two years, $12 for three years; Latin American countries, $15 for one year, $25 for two years, $30 for three years; all other countries $20 for one year, $30 for two years, $40 for three years. Entered as second class matter August 21, 1936, at the Post Office at Albany, N. Y., under act of Mar. 3, 1879. Printed in U. S. A. Copyright 1952 by McGraw-Hill Publishing Co., Inc.—All Rights Reserved.

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Highlights

When requesting further information from companies and organizations mentioned in the items below, confusion can be avoided by refering to the issue of Product Engineering in which items appear

METALLIC MATERIALS

GAS REMOVAL from molten aluminum alloys to control casting porosity is a matter of adding a proprietary mixture if microscopic examination indicates increasing porosity. Since porosity develops slowly, the additive (0.1 percent by weight of melt) is applied throughout a period of a day or more. If examination shows a decreasing trend in porosities, no additive is needed.

STAINLESS STEELS highly alloyed with copper, molybdenum, nickel and chromium show excellent corrosion resistance to a wide range of sulfuric acid concentrations. Control of composition and annealing at temperatures between 1,900 and 2,100 F are recommended for these weldable alloys. Tests at the Worthington Corp., Harrison, N.J. were made on sample pipe or valves while under normal service conditions.

BRAZING POWDER, has been recently developed by American Electro Metal Corp. of Yonkers, N.Y., for very high temperature brazing of molybdenum and tungsten electronic components. The powder melts at about 3,450 F, and forms a continuous braze upon solidifying.

AN INCREASE IN DEMAND varying from 27 percent for aluminum is estimated by the Materials Policy Commission for the 25 year period ending 1975. The 800-page report also states that cobalt, which is required for jet engine alloys, is expected to experience a 340-percent jump.

MOLYBDENUM'S MELTING TEMPERATURE, 4,750 F, and thermal conductivity, seven times austenitic stainless, make it attractive to designers for use as structurals in gas turbine and ramjet engines. If stresses are not excessive, such alloys can be used in the 3,000 F range and welded with helium-shielded tungsten electrodes in the absence of air. Weld reinforcement is needed in parts that are formed after welding.

ELECTROLYTIC MANGANESE from low-grade domestic ores can be substituted for some uses of ferromanganese made from high-grade foreign ores. According to a report from the Bureau of Mines, electrolytic product is desirable for stainless steels and welding rods because of its virtual freedom from phosporus and carbon.

SAVINGS IN STRATEGIC ALLOYS up to 85 percent have resulted from the use of ferritic welding rods instead of austenitic rods at the Detroit Arsenal. Rods are low in hydrogen and have a coating that contains all major alloying elements. Such welds stand up well in military vehicles subject to bombardment.

NONMETALLIC MATERIALS

FREQUENT CLEANING of equipment in contact with perishables such as foodstuffs may become "infrequent" if DuPont's new mildew-resisting enamel is used. Cunilate fungicide (copper-8-quinolinolate) is the key ingredient, is non-toxic and imparts a greenish-yellow cast to the finish.

TWIN PROBLEMS --shrinkage and swelling --in oil resistant rubber applications are reported minimized by Buna N compound X-1692 made by Acushnet Process Co., New Bedford, Mass. 70-hr tests in low and high aniline point oils resulted in only 12.5 percent swelling and 3.0 percent shrinkage without becoming tacky.

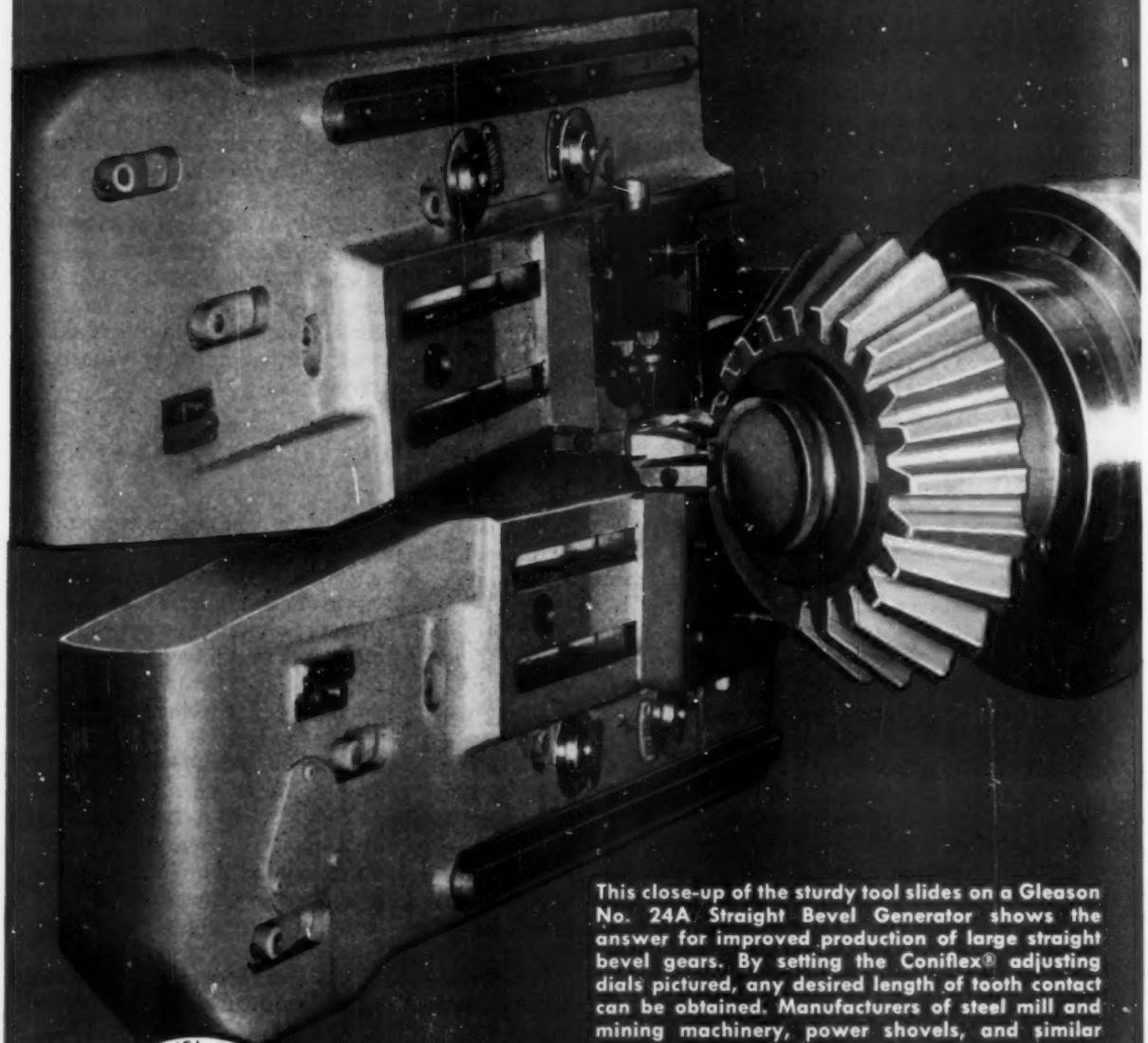
SILICONE-BASE FINISH is reported to withstand temperatures to 1,000 F without blistering, peeling or discoloring. John Zink Co. of Tulsa, Okla. is using Sicon, which is made by the Midland Industrial Finishes Co. of Waukegan, Ill., in gas heaters, both on combustion chambers and in various colors on outer surfaces.

THERMOSETTING LAMINATE combining high arc resistance with good mechanical properties has been developed by Synthane Corp. of Oaks, Pa. The G-8 plastic presents a saving in cost

(continued on page 7)

THE ANSWER

FOR BETTER LARGE STRAIGHT BEVEL GEARS



This close-up of the sturdy tool slides on a Gleason No. 24A Straight Bevel Generator shows the answer for improved production of large straight bevel gears. By setting the Coniflex® adjusting dials pictured, any desired length of tooth contact can be obtained. Manufacturers of steel mill and mining machinery, power shovels, and similar heavy-duty equipment are using Coniflex gears, with tooth contact suited for the application, for easier assembly, smoother operation, and longer life.

Send us details of your large straight bevel gear applications. We will gladly show you how Coniflex gears, cut on the No. 24A, will improve your results.

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below the continuous filament glass base material (NEMA Grade G-5) while matching its electrical properties. Laminated in thicknesses from 1/16-in. upward, material consists of a glass fiber mate impregnated with melamine resins.

HIGH-ALUMINA CERAMIC exhibits desirable mechanical, electrical and heat-shock properties that suggest many applications. Frenchtown Porcelain Co. of Trenton, N.J. lists among the potential uses of their Alamanox 4462 material: Envelopes on vacuum tubes, inserts for rocket nozzles, brake liners for jet bombers, bases for printed circuits, thread guided, and insulation for high-voltage equipment.

AN ALUMINUM COATING that can be sprayed without spattering surfaces four feet or more in the background is the development of Royston Laboratories, Inc., Blawnox, Pa. Special vehicle and solvents in Roylac aluminum cause it to dry to a cottony, non-adhering powder once the droplets have traveled more than four feet from the nozzle of the gun.

PROCESSES

SUBSTANTIAL PROGRESS is being made with cast magnesium aircraft wings at Northrop Aircraft, Inc. A section of a wing 16 ft. long and adhering to exacting tolerances has already been cast. Significance is attached to this project because it is believed that cast wings can be produced more rapidly and economically than can wings fabricated by attaching aluminum skins to spars and ribs with rivets or spot welds.

LOW-PH NICKEL STRIKE, which proved itself so valuable as an alternate for cyanide copper strike on steel prior to bright nickel plating, is proving equally valuable in getting satisfactory adhesion of bright nickel to unbuffed bright acid copper. Frederic B. Stevens Inc., Detroit 16, says the nickel strike solves the problem so completely that a growing use of this application is anticipated.

GREAT VALUE is to be derived from working with metals in frigid temperatures. According to Arthur D. Little, Inc., Cambridge, Mass., an extremely hard stainless steel has been produced experimentally by immersion in liquid nitrogen at -320 F, followed by rolling and forging at controlled temperatures. About 50 laboratories are equipped to do this "cold research."

WHEN MAGNESIUM IS WORKED at temperatures ranging from 450 to 700 F, it is possible to do in a single draw what would require up to three drawing operations in ferrous and some nonferrous metals. Allowable deformation increases more rapidly in magnesium with increase in temperature than in any other commercial metal, and springback decreases as temperature increases. There is no springback at 600 F.

LAST YEAR only 1,000 tons of aluminum were used for hot dip aluminized steel. By 1960, says Kaiser Aluminum & Chemical Corp., the figure should be closed to 80,000 tons annually. The aluminizing industry is growing, but will have to work hard to compete with galvanizing, and possibly, tin plate; and that the economics of the hot dip aluminizing process are closely allied with the methods of applying the coating.

AFTER EXTENSIVE TESTING, a special method of cold galvanizing for surface protection of steel and iron has been announced by the Galvanite Corp., New York City. The process involves a compound called Galvanite, which can be applied with brush, electric spray gun or by cold dip. Coating differs basically from other so-called metallic paints containing zinc in that it combines with the base metal, setting up electrical continuity and thus cathodic protection.

COMPONENTS

SEMICONDUCTING TITANIUM OXIDE in a single layer, a sheet of titanium metal and a counter-electrode of some other conductor promise to effect a major improvement in rectifiers. Experimental units at the National Bureau of Standards withstand a reverse potential of about 20 v per plate and performance improves as temperature is increased to about 150 Centigrade.

THE RECOIL of starter springs produced by Sandsteel Spring Div. of Sandvik Steel, Inc. is such that performance and service life on power saws, small tractors and power lawn mowers are satisfactory. Annealing procedure and high carbon steel are the key factors.

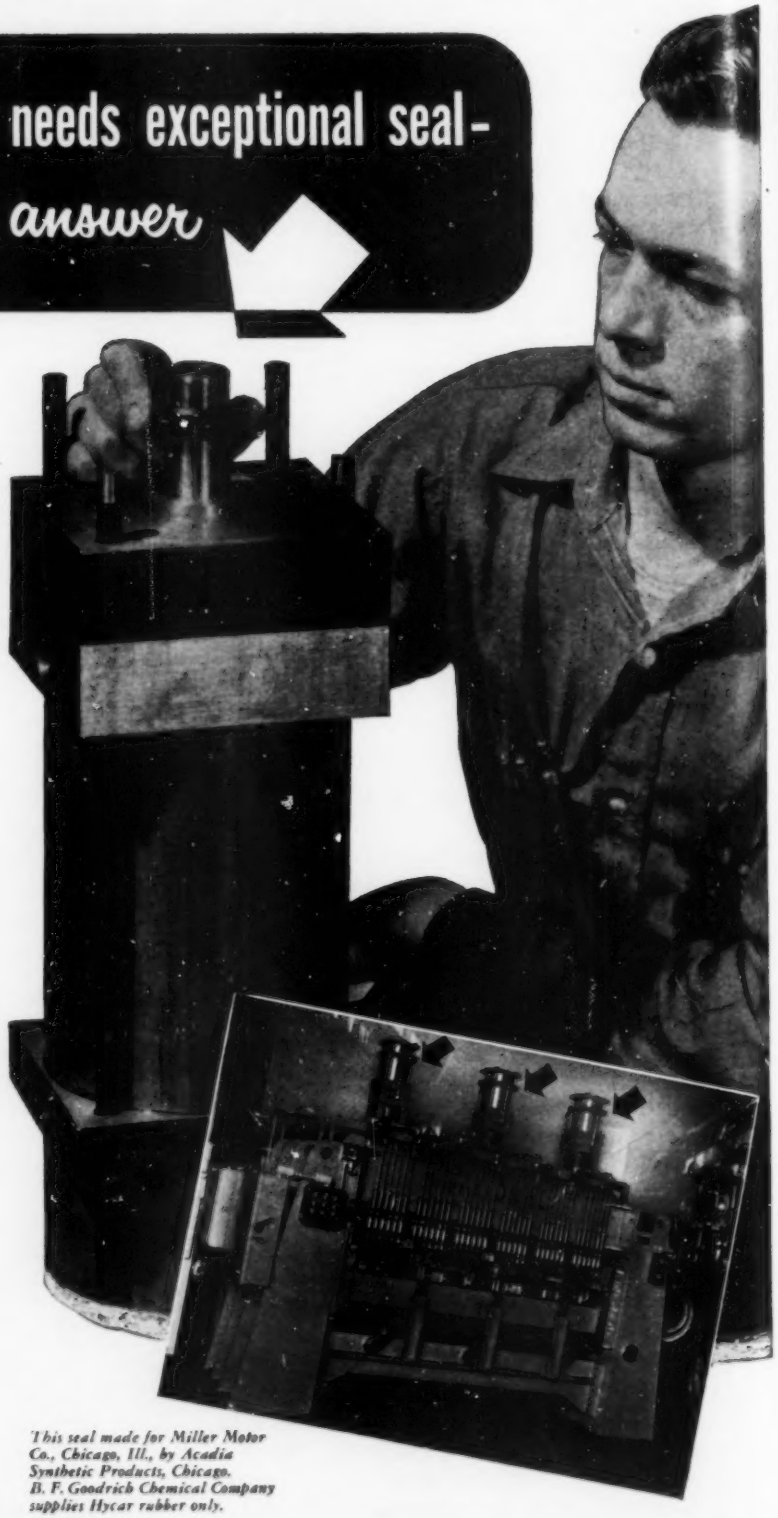
AN EXPLOSION-PROOF, remote-indicating fuel Flowrator, which shows an average deviation of less than 0.2 percent, has been developed by

(continued on page 9)

Another new development using

B. F. Goodrich Chemical *raw materials*

Pressure booster needs exceptional seal— Hycar's the answer



THESE fluid pressure boosters develop output pressures up to 10,000 p.s.i.—must have an absolutely leak-proof seal. More than that, the seal material must not change in volume or deteriorate in hydraulic oil . . . be affected by normal operating temperature . . . or distort or cold flow under extreme pressure. On every count, the seal manufacturer found Hycar rubber fills the bill perfectly!

Meeting unusual requirements like these is an every-day job for Hycar. For this versatile material can be made resistant to heat and cold . . . abrasion . . . oil, grease, gas, many chemicals and more rugged service conditions.

Perhaps one of the many Hycar rubber compounds can help you improve or develop a product—or solve troublesome, costly problems. Write for helpful technical bulletins and advice. Please address Dept. HP-5, B. F. Goodrich Chemical Company, Rose Building, Cleveland 15, Ohio. In Canada: Kitchener, Ontario. Cable address: Goodchemco.

B. F. Goodrich Chemical Company
A Division of The B. F. Goodrich Company

Hycar
American Rubber

This seal made for Miller Motor Co., Chicago, Ill., by Acadia Synthetic Products, Chicago. B. F. Goodrich Chemical Company supplies Hycar rubber only.

GEON polyvinyl materials • HYCAR American rubber • GOOD-RITE chemicals and plasticizers • HARMON organic colors

Fischer & Porter Co. of Hatboro, Pa. the Instrument will measure fuel flow rates from 160 to 65,000 lb per hr to an accuracy appreciably better than that or earlier glass-tube flow meters.

PRECHARGED PLATES that hold their life for several years are the feature of a new battery perfected by the Firestone Tire & Rubber Co. With a new glass separator and an acid bottle that holds the electrolyte, the battery, when activated by the acid, is said to deliver full power.

A FAST GROWING FIELD for nylon is in rivets and insulating fasteners for electrical components and assemblies. Nylon's combination of resiliency, toughness and temperature resistance has permitted radical changes in the design of components, according to The Polymer Corp. of Pennsylvania, makers of Polypenco nylon rod.

BRAZED ALUMINUM RADIATORS are being tested by General Motors in Chevrolets. They are more expensive than copper assemblies because the salt bath used in costly and numerous voids must be repaired. Also, there is no available solder compatible with coolant solutions. But, aluminum's low weight, availability, ability to take coolants under pressure and good heat transfer favor continued study.

TESTING

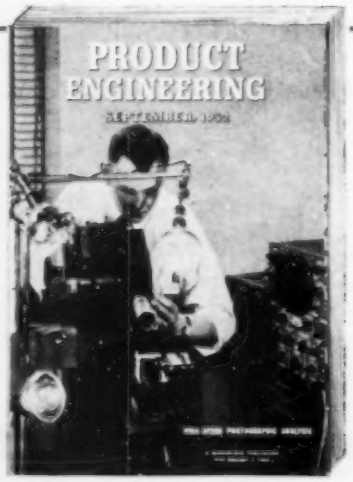
A TINY GEIGER COUNTER that does not require batteries is available from Morgan Instruments Co., Canoga Park, Calif. The Geiger-Mite consists of a generator, which fits in the palm of the hand and supersensitive head-phones.

EARLY OBSERVATIONS made with a huge siren by two physicists at the University of California in Los Angeles reveal that the higher the frequency or intensity of sound, the greater the percentage of sound energy converted into heat energy. The research has also demonstrated that, after a short period, sound waves of high intensity take on shock-wave characteristics, emphasizing a correlation between acoustics and aerodynamics heretofore little explored.

A MOISTURE DETECTOR that can look inside sealed packages and even cocooned aircraft is being studied by the Air Force. The Hydrotector, developed by American Instrument Co. of Silver Spring, Md. tells whether a package seal is good or bad, and whether or not the dessicant is keeping moisture within safe limits.

AN ELECTRONIC TROUBLE SHOOTER will soon be in operation at TVA's power plant. SARA (Sequential Automatic Recorder and Annunciator) will provide a continuous record of normal operations, as well as any deviations, in transformers, boilers, turbines, and circuit breakers.

THE ELECTRON MICROSCOPE is exposing the secrets to many problems of long standing at Chrysler's engineering labs. In early tests, rubber shock absorber bushings failed in some cases, not in others. The new microscope revealed that carbon black in all rubber compounds tested had large particles arranged in a network structure, whereas the best compounds contained another type of carbon black consisting of very small particles. Examination of the inferior type revealed only the network containing large-size particles.



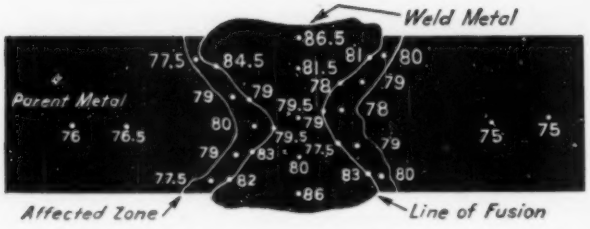
THIS MONTH'S COVER

Photography is quicker and generally more convincing than theoretical computations of inertia, acceleration, friction, elasticity and the like. In studying fast-moving mechanisms, a high speed movie camera never makes the mistake of neglecting factors that should not have been neglected. The picture on this month's cover shows a Kodak High Speed Camera making 3,200 pictures per second of a solenoid valve in action. Simultaneously, a second lens on the side of the camera records through the back of the film an oscillogram of the electrical impulses fed to the solenoid. Also simultaneously, an argon lamp inside the camera puts a timing signal on the film. When the film is shown in an ordinary movie projector at 16 frames per second, design engineers see at 1/200 of actual speed exactly what happens when the solenoid is energized, how long it takes the mass to start moving, when the contacts close completely, and how soon the solenoid is ready to re-cycle.

The special report starting on page 167 contains a thorough discussion of the various high speed photographic techniques and cameras, and shows some of the uses to which this versatile design tool has been put.

Kodachrome by Robert Phillips, Eastman Kodak Company

This Low-Alloy High-Strength Steel Welds as Readily as Carbon Grades



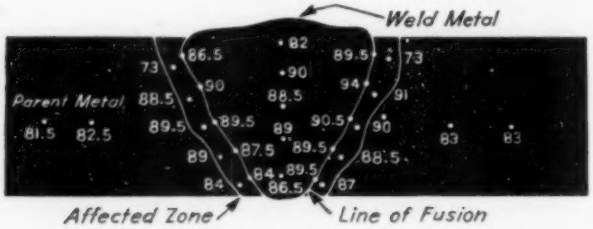
Rockwell B hardness on ½-in. manual arc-welded plate of Mayari R, stress-relieved at 1050 deg F.

Mayari R is a low-alloy, high-strength steel that can be welded by the ordinary methods used for plain carbon steel . . . electric-resistance, including spot-, seam-, and flash-butt . . . electric-arc, including metallic, carbon, and inert-arc . . . automatic-submerged-arc . . . and gas-welding processes.

There is no difference in the equipment, the technique, or the welding speed with Mayari R.

A non-air-hardening grade, Mayari R shows no appreciable hardening from welding temperatures. Results of tests made on welded Mayari R indicate that the welds are equally as strong as the parent metal.

Full information on welding and fabricating this steel is readily available for your files. Write or phone any Bethlehem sales office and ask for a copy of Mayari R Catalog 259.



Rockwell B hardness on ¼-in. manual arc-welded Mayari R plate, as welded.

BETHLEHEM STEEL COMPANY, BETHLEHEM, PA.

On the Pacific Coast Bethlehem products are sold by Bethlehem Pacific Coast Steel Corporation. Export Distributor: Bethlehem Steel Export Corporation

★ BETHLEHEM STEEL ★

Mayari R *makes it lighter... stronger... longer lasting*

Perspectives ~ DESIGN AND DEVELOPMENT

AIR FORCE DPA FEUD

The Defense Production Administration's feud with the Air Force and Navy over combat aircraft may result in a complete turn-about for aircraft designers.

There's a lot more to the row, but one of major changes DPA is seeking in aircraft production is a greater concentration by engineers and technical experts of the services and industry on completely new warplanes. The armed forces are wasting too much of the time of these professionals, DPA feels, by swamping them with demands for improving obsolescing models and in making only minor changes in new aircraft.

DPA TARGET

There have been a lot of allegations, mostly from the Defense Department, that what DPA wanted was for the services to freeze aircraft models and to standardize plane and engine designs to get an immediate boost in production. There may be some truth in this supposition, but the real target of DPA criticism was Air Force and Navy procurement policies and procedures.

Virtually every military order for fighters and bombers then on the books would have been affected had the services accepted suggestions made by DPA early in July. Production of some planes and engines would have been increased, output of others would have been slowed, and contracts for still more would have been cancelled entirely. But these recomendations were secondary -- merely suggestions by DPA as to how some of its primary proposals could be carried out.

Here are the major changes in aircraft procurement urged by the mobilization agency:

1. Eliminate production of multiple types of aircraft designed for the same combat mission and concentrate on the best ship for the purpose. That is, the best day fighter, the best night fighter, the best fighter-bomber, the best interceptor, and so on.

2. Cut red tape that slows production of new models.

The first recommendation applied only to aircraft already in production or soon to go into production. It involved no entirely new designs still on the engineers' drawing boards. But it was aimed at developmental work on such models as the North American F-86-H fighter, a souped-up version of the F-86-F Sabrejet. The "H" model would have a more powerful engine than the "F". DPA'S recommendation here was to drop production plans for the F-86-H, concentrate engineering on a plane designed specifically for a bigger power plant -- like North American's F-100, which is still months away from production.

CUTTING RED TAPE

Some of the red tape DPA wants cut includes:

1. Military inspection boards, which pass on prototypes of new aircraft. These boards sometimes number sixty or more members who have to reach unanimous agreement before accepting a new model. Individual board members frequently hold out for pet improvements of a trifling nature. When these improvements are numerous they often force complete redesign before the aircraft can go into production.

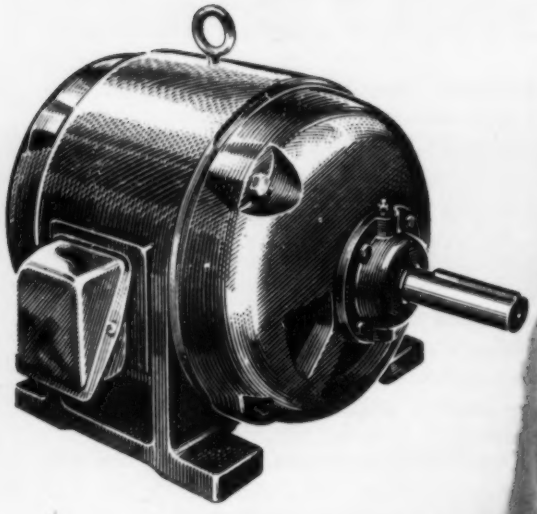
2. Delays in letting contracts: In September, 1948, for example, the Air Force tested a prototype of the convair F-102, which it rated as the

(Continued on page 115)

ELECTRO DYNAMIC

INDUSTRIAL MOTORS

Bred for BRAWN



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To give added years of dependable, low-cost operation, special skills and superior insulating materials are used to toughen the WINDINGS... "the heart of the motor." The frames and housings are of rugged cast construction for rigidity and resistance to corrosion.

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E. D. also makes a complete line of Direct Current Motors and Generators. Literature on request.

Industry has learned what marine engineers have known since 1880

ELECTRO DYNAMIC builds great motors

ELECTRO DYNAMIC • Division of General Dynamics Corporation • Bayonne, New Jersey

AUTHORIZED SERVICE IN PRINCIPAL CITIES

best looking interceptor in sight. Yet today it still has not placed orders for as many as a dozen 102 models.

3. Priority assignments: The services put their own urgency rating on weapons to guide their contractors as to the order in which they want deliveries. In many cases, Air Force and Navy priority ratings just didn't make sense to DPA. Example: The Navy has given a much higher rating to production of an obsolescent piston-engined bomber than to the jet-powered plane that is to replace it.

BEST PLANES AND ENGINES

DPA gave the Air Force and Navy a list of planes and engines on which they should concentrate both actual production and developmental work. In most cases, it recommended that the services step up output of the best of its present planes -- like the Air Force's F-86-F Sabrejet fighter and the Navy's A-3D twin-jet light bomber -- and cancel out production of all other planes being built for identical missions as soon as the favored aircraft are in production.

For the future, DPA wants the services to look more toward development of planes which military and industry experts rate as far superior to any we now have or that the communists have shown over Korea. In this direction, DPA went along with recommendations of the Defense Department's own research and development board on Air Force fighters. It obtained less formal, but just as authoritative, views on other aircraft types, DPA said.

On engines, DPA urged accelerated production and development on new, high-powered jets -- such as the J-57, J-71, J-73. These power plants generally have a rating of upwards of 10,000 lb thrust or more. DPA recommended a gradual cut-off of lower-powered engines generally as soon as the planes for which they are being made can be replaced by more modern types. It recommended cancellation of some lower-powered engines immediately on grounds that they would not be good enough even for present aircraft types or that production is so snarled that engines would be obsolescent before they could be delivered.

MILITARY VIEWPOINT

There is no expectation that all of the Defense Production Administration's recommendations will be accepted without a fight. Military experts are of the opinion that DPA is oversimplifying the process of selection of the best aircraft. Both the Air Force and the Navy feel that it is best to go slow on production schedules until exhaustive tests have proven that the plane selected is the one they want to live with for a considerable time.

The best testing condition in the opinion of the military is actual combat. Consequently they like to have four of five models performing the same task under the same combat conditions. This would make a final choice more expedient and more decisive.

If nothing else this recent wrangle will bring to light many of the faults of both views. No one will deny that we need a higher rate of production of combat aircraft. Whatever the snags are they will have to be removed before this is possible.

MATERIALS SUPPLY EFFECTS

If DPA'S recommendations are accepted, the expected increased plane production could result in increased consumption of aluminum and copper. This would be advantageous, especially in the case of aluminum, since normal consumption of these materials has been restricted by lack of steel caused by the recent strike.

Some concern exists that an increase in aircraft production could result in the Air Force running out of funds to back up contracts. In such a case, top defense production officials will take the matter directly to the President and seek supplemental appropriation in Congress. No serious opposition to such an appropriation is anticipated.

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A
B
C
THE OLD METHOD
Riveted attaching clip A, die cast collar B, special bracket piece C, were required to assemble grille, reflector cone assembly, and motor mount brackets to motor housing.
SPEED NUT METHOD
Special SPEED NUT and redesigned motor mount bracket eliminate A, B, and C. Permit direct attachment of grille and reflector cone assembly to motor housing.
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Requirements for Bearing Materials

1. COMPATIBILITY

Compatibility is a measure of the anti-weld characteristics of a bearing material when operated with a given journal material.

Metal to metal contact exists frequently even in well lubricated journal bearings. Upon starting, the rotating journal slides on the bearing until an oil film is generated to separate the surfaces. Direct contact also exists sometimes in misaligned bearings and at high spots. In such cases the degree of welding and tearing that occurs is intimately associated with the mechanical, chemical, and metallurgical properties of the metals.

2. EMBEDDABILITY AND CONFORMABILITY

The hardness and modulus of elasticity of a bearing material should be as low as possible while providing sufficient strength to carry the applied loads. The resulting characteristics enable a bearing to compensate for misalignment and to conform to other geometric errors.

When a journal forces dirt or wear particles against a bearing material, it is also important that the material absorb the foreign particles and thus avoid scoring and wear. A recent experimental evaluation of embeddability ranks the bearing material in the same order as would be anticipated from Fig. 2, which lists elasticity data.

3. CORROSION RESISTANCE

Some metals react readily with the organic acids formed in lubricating oils during their oxidation. As a result, rapid corrosion occurs and insoluble organic soaps of the bearing materials are deposited in the system. This tendency is most objectional at high temperatures and when the ratio of the quantity of oil to the bearing surface is low as in electric clock and other fractional-horsepower motors.

Materials containing lead, cadmium, zinc, and copper are most susceptible to this type of corrosion. Difficulties can be minimized by selecting oils with good oxidation inhibitors, and by specifying periodic oil changes. Relative rates of corrosion of several materials are shown in Fig. 3. Studies now under way indicate that aluminum and tin-base babbits are quite resistant to corrosion, while lead-base babbits must contain at least 10 percent tin to avoid relatively rapid attack.

4. COMPRESSIVE AND FATIGUE STRENGTH

Fatigue strength is particularly important in applications for which the load changes direction, such as in reciprocating engines. Table I gives comparative data for several bearing materials.

Materials of intermediate compressive strength generally exhibit satisfactory resistance to extrusion without having the brittleness which would cause crumbling under shock loads. Sufficiently high fatigue strength will enable a bearing to operate without developing cracks or surface chips. The use of a thin layer of soft bearing metal bonded to a hard backing metal often gives the desired combination of fatigue and compressive strength. In such cases the fatigue strength of the bond requires particular attention.

5. COST AND AVAILABILITY

Although the importance of cost cannot be ignored, in abnormal times availability can do much to offset it. Also, the current labor rates make it necessary to include processing in the ledger.

Selecting the Right Journal Bearing Material

E. H. SCOTT, JR.
E. R. BOOSER
Thomson Lab., General Electric Company

THROUGH PAST EXPERIENCE, certain basic requirements have been set forth for evaluating bearing materials. These are (1) compatibility (2) embeddability and conformability (3) corrosion resistance (4) compressive and fatigue strength (5) cost and availability.

Actually, this list is not complete. For some applications, factors such as bondability, machineability, coefficient of expansion, and thermal conductivity must be added. The important fact is, however, that no one material is equally good with respect to all requirements. Thus, selecting the proper material for a specific bearing must be based on those factors that are most essential for the given application.

Numerous investigators have compiled data on the properties of the commonly used materials, such as white metal alloys, copper base alloys, aluminum, silver, powdered metals, cemented carbides, cast iron, graphite, and plastics. Much of this work has been reviewed herein, and to it is added original information on compatibility characteristics as determined by the equipment shown in Fig. 1. In this tester, a one-quarter inch square piece of bearing material is pressed

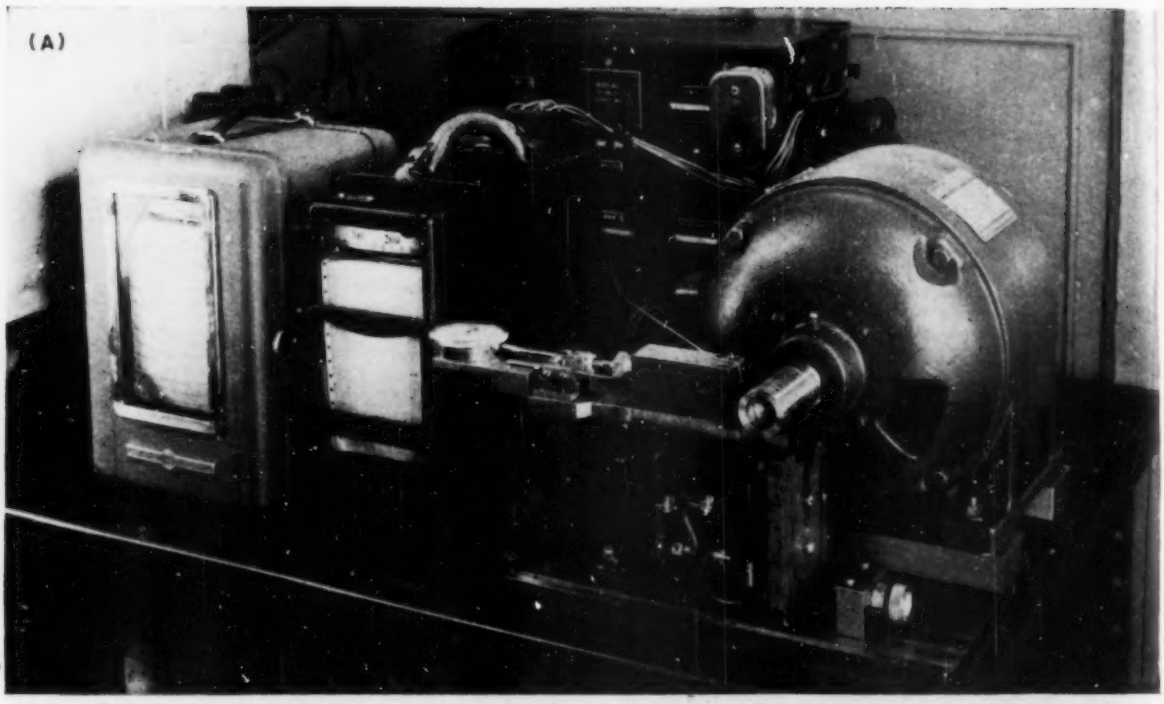
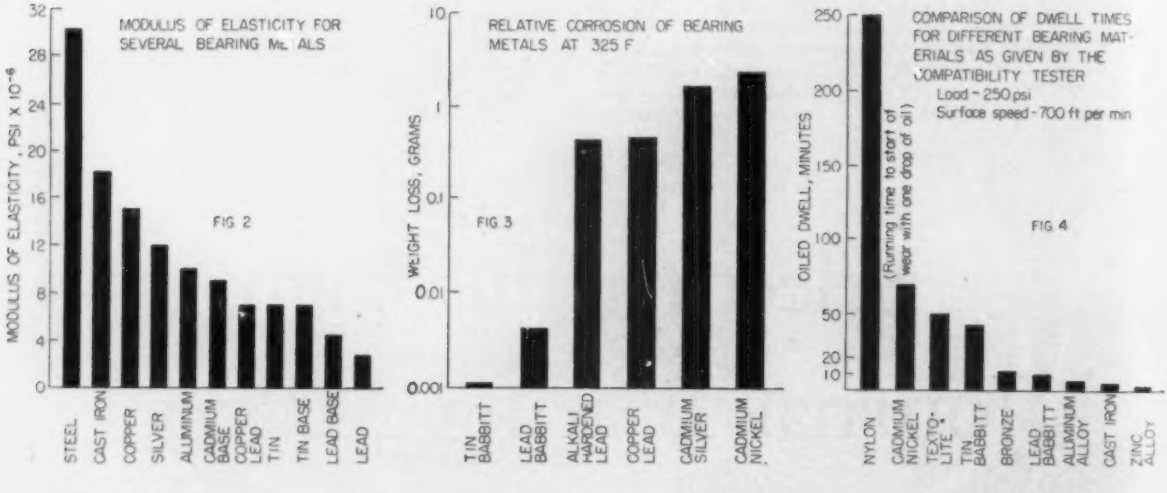


Fig. 1—(A) Compatibility tester used to get data on wear rate, coefficient of friction, and tendency of different bearing materials to score steel shafts. (B) Numerical coding system that was used to compare these compatibility characteristics.



under a given load against a 1½ in. diameter shaft rotating with a surface speed of 700 fpm. Measurements were made of the wear rate of the bearing material, temperature rise, and coefficient of friction. A numerical coding system illustrated in Fig. 1 (B) indicated the degree of pickup, scoring, and coloring of the ring as well as the mushrooming, scoring, and coloring of the test piece. The time elapsed, or "dwell" period, from the start of a test to the beginning of appreciable wear, is shown in Fig. 4.

White Metal Alloys

Tin and Lead Babbitt. A bearing material should have a minimum tendency toward surface damage when operated with a steel journal under conditions of boundry lubrication. The one metal that probably can fill this requirement best for most applications is babbitt. It has excellent compatibility and non-scoring characteristics plus outstanding embeddability and conformability.

Two types of babbitt are in common use. One is a tin-base, with about 4 to 7 percent copper and 4 to 12 percent antimony; the other is a lead-base with a maximum of 20 percent tin and 10 to 15 percent antimony. Better corrosion resistance, less tendency to weld under conditions of poor lubrication, and easier bonding to a steel shell generally make tin babbitt the more desirable. The high cost of tin and its critical shortage in times of emergency, however, have brought lead babbitt into use whenever possi-

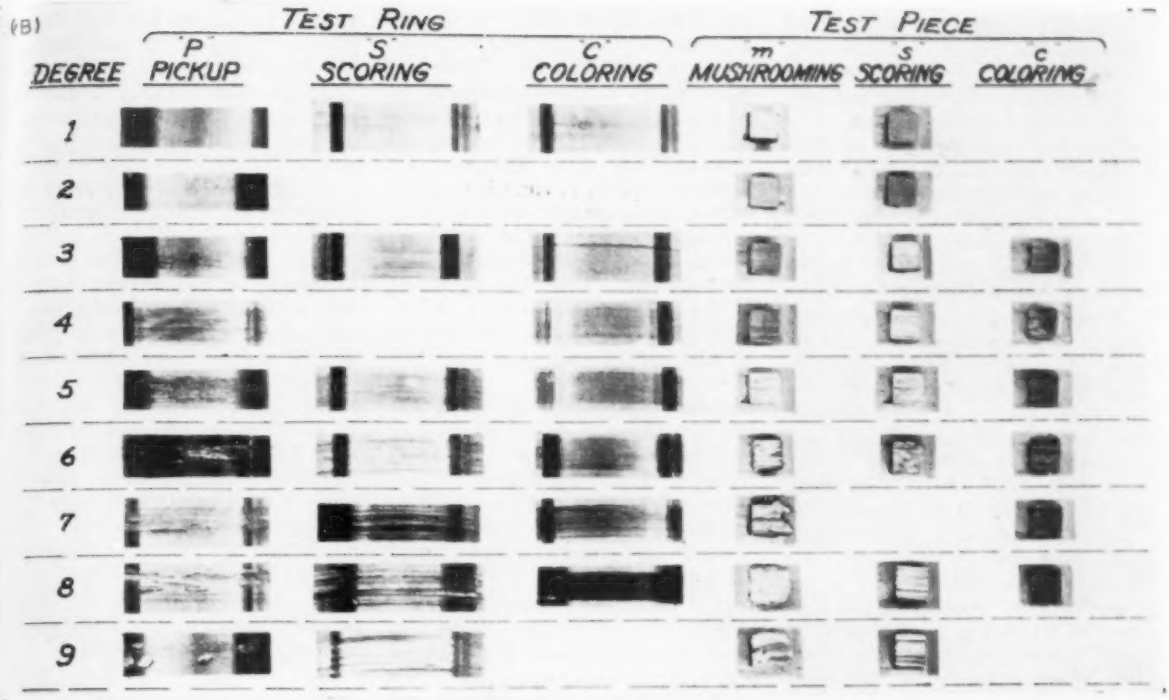


Table I—Summary of Properties of Common Bearing Materials

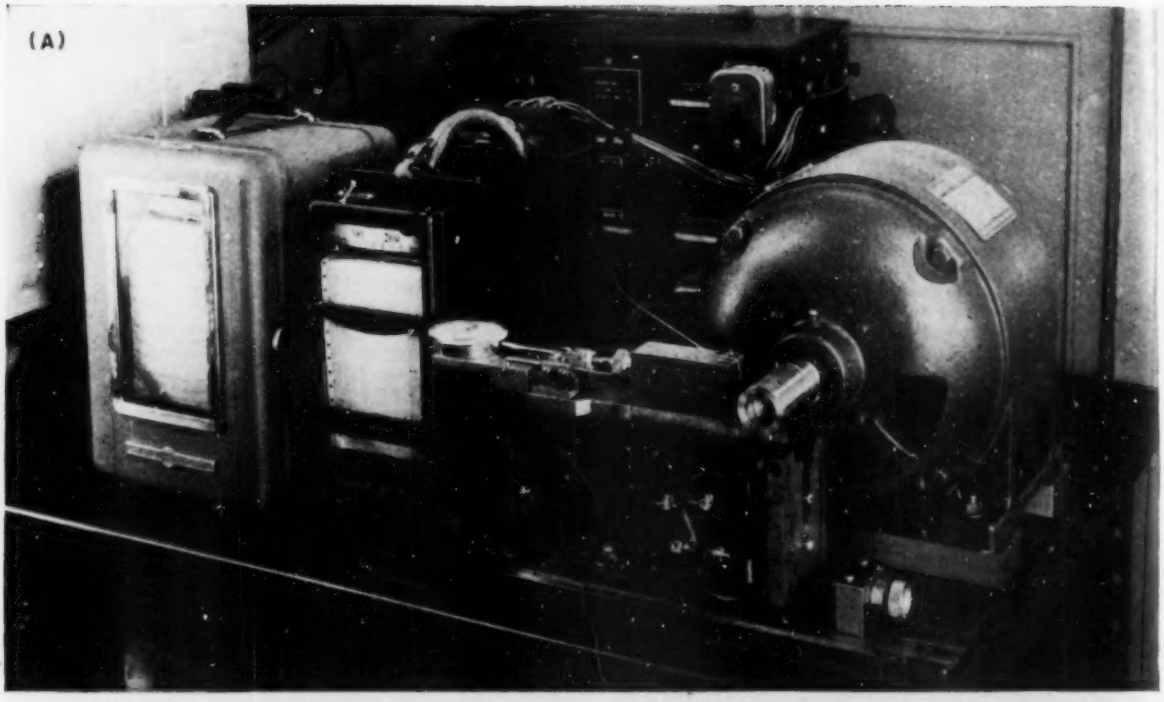
Material	Brinell Hardness		Min. Shaft Hardness Brinell	Load Capacity, psi	Max. Operating Temp., F	Compatibility *	Conformability—Embeddability *	Corrosion Resistance *	Fatigue Strength *
	Room Temp.	300 F							
Tin-Base Babbitt	20–30	6–12	150 or less	800–1,500	300	1	1	1	5
Lead-Base Babbitt	15–20	6–12	150 or less	800–1,200	300	1	1	3	5
Three-Layer Composite (Babbitt)	.....	.....	230 or less	2,000–4,000	225–300	1	2	2	3
Alkali Hardened Lead	22–26	11–17	200–250	1,200–1,500	500	2	1	5	5
Cadmium Base	30–40	15	200–250	1,500–2,000	500	1	2	5	4
Copper-Lead	20–30	20–23	300	1,500–2,500	350	2	2	5	3
Tin Bronze	60–80	60–70	300–400	4,000	500	3	5	2	1
Lead Bronze	40–80	40–60	300	3,000–4,500	450–500	3	4	4	2
Phosphor Bronze	75–100	65–100	400	4,000	500	3	5	3	1
Aluminum Alloy	45–50	40–45	300	4,000	225–300	5	3	1	2
Silver (Overplated)	25	25	300	4,000	500	2	3	1	1

* Arbitrary scale with 1 being the best material and 5 the worst.

ble, and there are many applications with non-corrosive oils for which it will perform as well as or better than tin babbitt. Antimony-arsenic-lead bearings have been giving excellent performance, for example, in large steam turbine thrust bearings. In these applications, the lead babbitt has shown less tendency to score the steel runners than did the tin babbitt used previously.

Compatibility tests indicate that tin babbit can run longer than lead babbit without damage after the oil supply fails. Field experience bears this claim out. Table II shows the dwell period or no-wear time interval for one lead to two tin alloys, and this also shows their relative wear rates. Although the lead babbitt wore excessively when run dry, its performance in the one-drop-of-oil tests was much better than that of the tin babbitts. The excessive dry-run wear was caused by heavy pickup or welding of the babbitt to the steel shaft. This created a rough surface which quickly wore away the bearing material. The low wear, together with the low friction and a lesser tendency for scoring indicates that under lubricated and some boundary-lubricated conditions, lead babbitt should perform as well as or better than tin babbitt if other factors, such as corrosion and fatigue strength, are within acceptable limits.

All babbitts, however, are inherently weak, and high temperatures reduce the strength even further. Therefore, they are usually bonded to a stronger backing material such as bronze or mild steel. Thickness of



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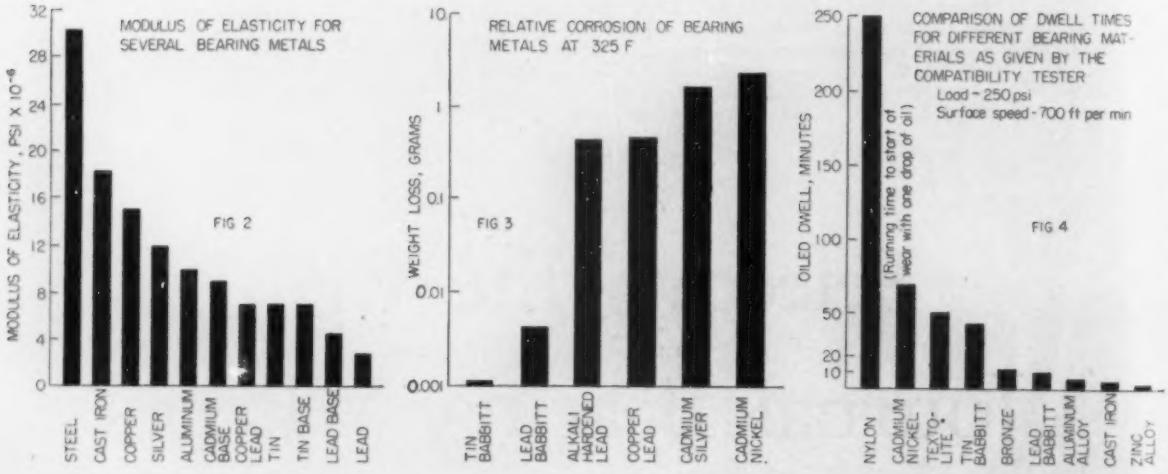

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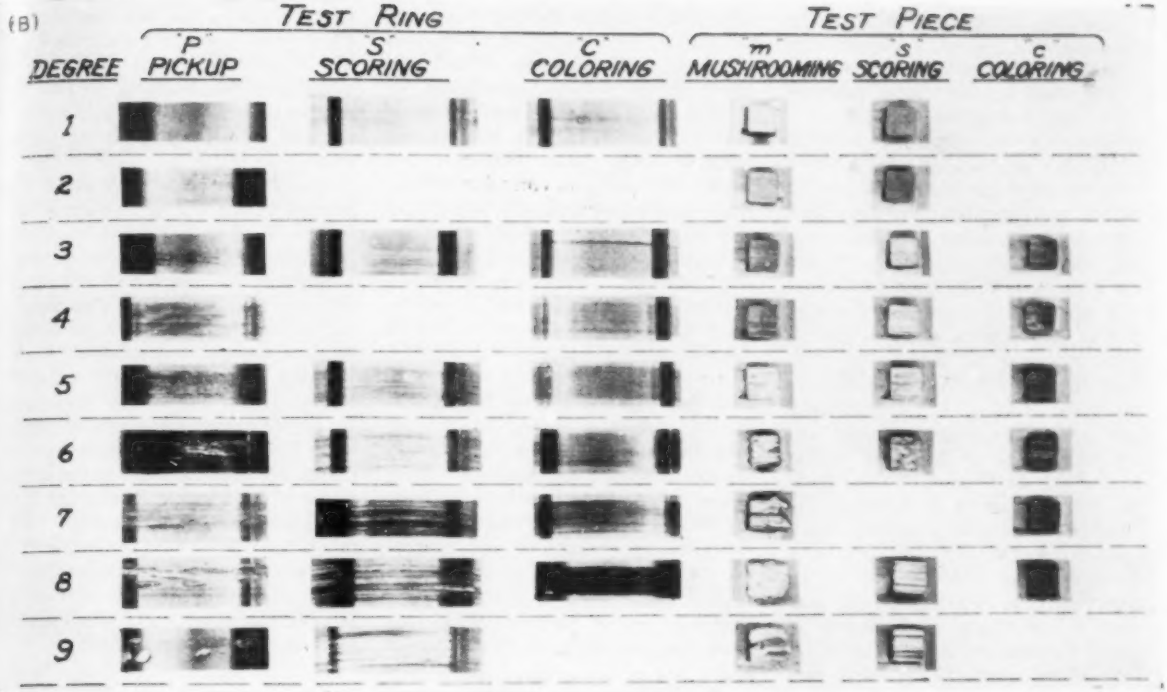

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All babbitts, however, are inherently weak, and high temperatures reduce the strength even further. Therefore, they are usually bonded to a stronger backing material such as bronze or mild steel. Thickness of

the babbitt lining varies with the application, but generally ranges from several mils in high output automotive engines to $\frac{1}{8}$ in. for turbine bearings. With thin linings, the strength is increased but conformability and embeddability are reduced. A thickness of 0.001 to 0.005 in. is indicated by Fig. 5 to be optimum for long bearing life; more recent experience suggests that life decreases if thicknesses less than about 0.001 in. are used.

A number of schemes have been used to improve the strength and fatigue resistance of babbitt bearings. Most of these involve (1) a low-carbon steel backing, (2) an intermediate layer of a copper or bronze, and (3) an overlay of lead-base babbitt from about 0.005 to 0.020 in. thick. The intermediate layer increases the strength and fatigue properties while maintaining the compatibility, embeddability and conformability of the babbitt overlay. Bearings of this construction are being used widely in diesel, automotive, and aircraft engines where reciprocating loads predominate. One—a copper-nickel matrix type—is produced by a continuous strip process in which powder of 60 percent copper and 40 percent nickel is deposited on a steel strip which then passes through a sintering furnace. Babbitt is vacuum-cast on the porous copper-nickel matrix to impregnate the pores and provide a surface overlay. Loads about 20 percent higher than with ordinary lead babbitt can be carried.

Tri-metal bearings use an intermediate layer of about 0.013 in. of either a copper-lead composition or a leaded bronze. This middle-layer is machine finished, and a thin overlay of babbitt is added by precision casting or plating. Load carrying capacity ranges up to 3,000 or 4,000 psi as compared with about 1,500 psi for babbitt.

Another composite bearing design, called the grid-type, uses a knurled intermediate layer of copper alloy or silver to which a lead-base babbitt layer is applied by either casting or electroplating. The surface is then machined to produce a final structure consisting of a grid-work filled with lead babbitt. Units of this type are now being used in some high output diesel engines for which the working loads are 4,000 psi or more.

Alkali-hardened Lead. Also classified as white metals, are alkali-hardened lead, zinc-base alloys, and cadmium-base alloys. Lead can be made as hard as babbitt by adding small quantities of calcium, tin, and mercury. This is similar to high-tin babbitt, except for a higher melting point and an ability to retain bearing properties at higher temperatures. There are other alloys similarly hardened by adding alkali and alkali-earth elements such as calcium, barium, sodium, and lithium. All these, however, are highly susceptible to corrosion and require careful control of casting and melting conditions. Also, they are difficult to recast without causing property changes. Therefore, they are looked upon only as possible substitutes when cost or non-availability of tin warrants their use.

Zinc-base Alloys. During World War II, the Germans made many zinc alloy bearings which gave satisfactory service in varied applications. These alloys are considered to be substitutes for bronze rather than babbitt, even though their appearance and properties are more like those of the latter.

One such alloy with 3 percent aluminum and 1 percent copper was given compatibility tests. It performed poorly, giving high wear, heavy pickup on the shaft steel, high friction, and short dwell times of only one or two minutes when run with one drop of oil.

Other zinc alloys were also tested; one having 4 percent aluminum and 0.03 percent-maximum copper, and another containing 4 percent aluminum and 1 percent copper. Like the German alloy, these exhibited high friction and wear because of welding to the shaft material. A common characteristic was the inconsistency of their behavior, possibly due to non-homogeneity of structure. The die-cast form seemed to be superior to the sand or mold-cast alloys, especially in the case of the 0.03 percent copper alloy which, when die cast, showed the best compatibility properties.

Zinc-base alloys containing several percent of copper and aluminum are reported to have been used successfully in many applications where loads are moderate and shaft speeds are above 200 rpm, or where loads are approximately 50 psi and speeds are less than 200 rpm. In these cases, alignment must be good and adequate clearance maintained.

Cadmium-base Alloys. Cadmium and steel have low affinity for each other; hence cadmium would be expected to have good compatibility characteristics. It is generally alloyed with 1.0 to 1.5 percent nickel, or 0.40 to 0.75 percent copper and 0.50 to 2.00 silver. These alloys are usually equal to babbitts and surpass them in the high-operating-temperature range. Their disadvantage lies in the fact that they are even more susceptible than lead babbitt to corrosive attack. Diffusing indium into the working surface and heat treatment helps, but also increases the cost of a bearing already expensive.

A cadmium alloy with about 1.35 percent nickel, was given compatibility tests on both soft and hardened steel. In both cases, it showed an outstanding ability to run without wear for over an hour with only one drop of oil, and ten minutes with no lubrication. It showed less tendency toward welding or pickup than tin babbitt, but generally scored the steel more. Its ability to run for extended periods with little or no lubrication explains its successful application to equipment where hydrodynamic lubrication is intermittent or entirely lacking. Cadmium has found use, for instance, in roll neck bearing in rolling mills. High cost and limited availability, however, have prevented much general interest from being aroused.

Copper-Base Alloys

Copper-lead. The simplest type of copper-base bearing is the binary copper-lead type which may contain as much as 40 percent lead. In such a material, up to 5 percent silver is often added to overcome the tendency of lead to segregate. Uniformity of the size, and dispersion of the pockets of lead in the copper matrix become increasingly difficult to maintain as the lead content is increased. Hardness of copper-lead castings is no higher than that of the babbitts at room temperature, but it is higher when the temperature approaches 300 F. Although the fatigue strength is greater than that of babbitt, a steel backing usually is used for increased strength. Their good fatigue strength and generally good bearing properties have led to use in automotive and aircraft engines, and in some Diesels.

The theory of operation of these bearings is that the lead is smeared by the journal to form a thin layer over the entire surface. If this layer is worn through, new pockets of lead are exposed to restore the surface. A plating of indium, followed by its diffusion into the lead, is desirable for protection under corrosive conditions. A thin plate of lead-tin mixture sometimes is applied to alloys containing up to 30 percent lead. With higher lead contents, it is not considered necessary.

Two alloys (70 percent copper with 30 percent lead, and 75 percent copper with 25 percent lead) were given compatibility tests and average dwell

periods of 25 and 22 minutes, respectively, were obtained. Pick-up and scoring were very mild, but the material wore away rapidly once the dwell period was passed.

Leaded Bronze. The leaded bronzes have lead contents ranging from about 5 to 25 percent and contain about 10 percent tin. The tin gives better strength and fatigue resistance and higher hardnesses than are possible with copper-lead alloys. Hardness ranges from about 40 to 80 Brinell. Zinc sometimes is used as a replacement for tin; nickel or nickel and silver are often added to reduce susceptibility to corrosion.

The strength of leaded bronze is limited at high temperatures by the weakening of the lead between the copper-tin grains and performance is not considered satisfactory at temperatures above 450 to 500 F. since the lead tends to bleed from the alloy. Hardened shafts are recommended for use with all bronzes.

Tin Bronze. When the tin content is increased to from 10 to 20 percent, and lead is added in amounts up to 10 percent to aid machineability, the alloy is classified as tin bronze. Small amounts of zinc, nickel, or both, are sometimes included where great strength is required. Hardnesses of 170 Brinell are possible, in which case the bronze is very brittle and has poor bearing properties. Alloys having intermediate amounts of tin are extremely useful where loads are 5,000 psi or more. But since their bearing properties are relatively poor, all tin bronze bearings require good alignment and reliable lubrication, as well as a minimum shaft hardness of 300 to 400 Brinell.

These bronzes are used for cast bushings in large volumes because they offer: (1) adequate bearing properties; (2) excellent casting and machining characteristics; (3) good economy; and (4) the desirable absence of a bond to fail or a lining to wear through. Since alloys with a wide range of properties have been developed, selection of the best one for a given application is usually quite involved. Also, it must be remembered that variations caused by different methods of manufacture are often greater than those caused by composition changes. The methods used for casting, chilling, machining, broaching, furnishing, etc., can have pronounced effects upon the compatibility characteristics as well as upon other physical properties.

A study of wear rate was made on several alloys containing basically only the metals copper, tin and lead, including two copper-leads. The rate of wear and scoring are compared with composition on a triangular coordinate graph shown in Fig. 6. A region of lowest wear was found in the vicinity of the composition 8 percent tin, 19 percent lead, balance copper. In almost every case where the wear rate was low, however, the scoring tendency was high. The materials which showed high wear, on

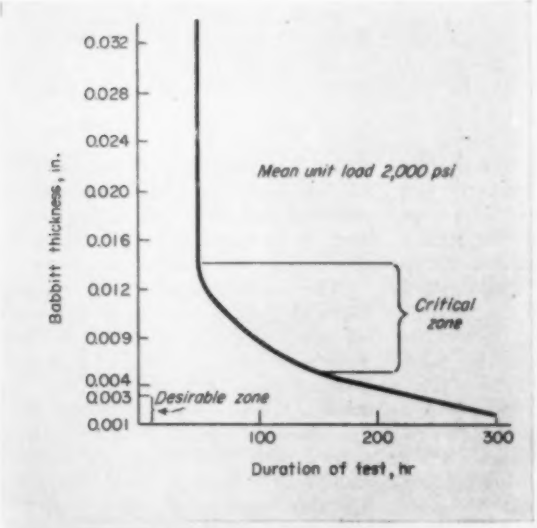

Fig. 5—Effect of babbit liner thickness on the useful life of bearings for reciprocating type engines.

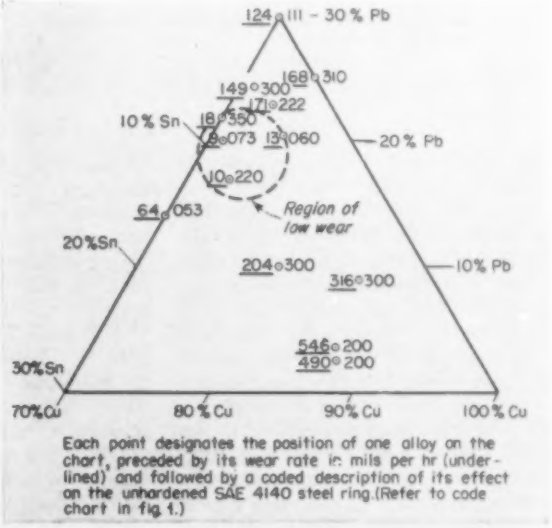
124 o 111 – 30 % Pb
168 o 310
149 o 300
171 o 222
10 % Sn
181 o 350
20 % Pb
10 o 220
64 o 053
Region of low wear
20 %Sn
204 o 300
316 o 300
10 % Pb
546 o 200
490 o 200
30% Sn
70%Cu
80 % Cu
90% Cu
100 % Cu
Each point designates the position of one alloy on the chart, preceded by its wear rate in mils per hr (underlined) and followed by a coded description of its effect on the unhardened SAE 4140 steel ring. (Refer to code chart in fig. 1.)

Fig. 6—Bronze composition on triangular coordinates shows wear effects. Derived from compatibility data.

Table II—Averaged Compatibility Data for Tin and Lead Base Babbitts*

Material	Lubrication	Load, psi	No. of Tests	Wear Rate, in./hr	Max. Temp, deg F	Coef. of Friction	Dwell Time, min
Tin Babbitt 89Sn, 7.5Sb, 3.5Cu	None	340	4	0.042	351	0.34	0
	1 drop oil	250	3	0.029	262	0.36	49
Tin Babbitt 83.3 Sn, 8.3 Sb, 8.3Cu	None	340	2	0.080	396	0.28	0
	1 drop oil	250	3	0.031	277	0.27	35
Lead Babbitt 76.5Pb, 15Sb, 0.5Cu 7.5Sn, 0.5As	None	340	3	1.673	320	0.34	0
	1 drop oil	250	3	0.001	149	0.17	10

* Run against unhardened SAE 4140 shaft steel ground to 8–16 rms microinches.

Table III—Averaged Compatibility Data for Bronzes*

Alloy	Dry Wear Rate, in./hr	Dry Coef. of friction	Oiled Dwell, min.
Tin Bronze...	0.067	0.36	3
Lead Bronze..	0.102	0.22	8
Zinc Bronze..	0.010	0.44	151

* 250 psi load; 700 ft/min surface speed, unhardened 4140 shaft steel with F 3 finish

Table IV—Compatibility Data For Aluminum Alloys*

Alloy	Wear Rate in./hr	Coef. of Friction	Dwell, min.
87.8Al, 8Si, 3.5Cu 0.7Fe	0.05	0.25	2
	8.2**	0.45**	1**
95Al, 4Si, 1Cd	0.09	0.30	1**
91.5Al, 6.5Sn, 1Ni 1Cu	0.30	0.33	3
Dural	0.03	0.30	0

* Unhardened 4140 shaft steel; F 3 finish; 250 psi load 700 ft/min surface speed; lubricated with one drop of oil.
** Run dry at 340 psi

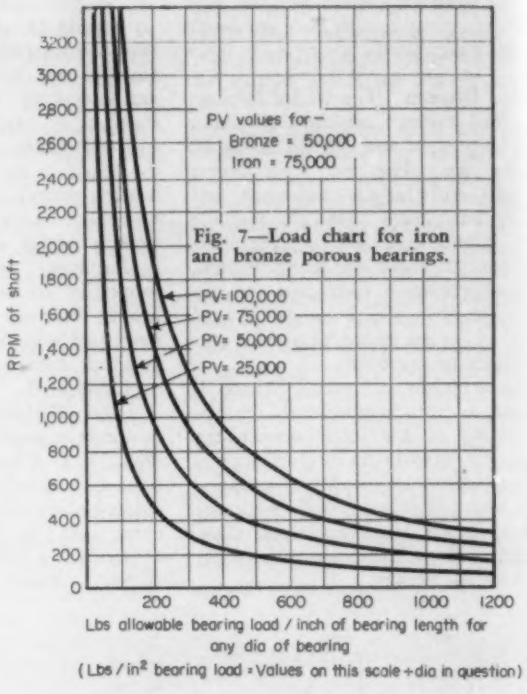

Fig. 7—Load chart for iron and bronze porous bearings.

the other hand, generally exhibited little or no scoring.

A summary of the compatibility tests with bronze is given in Table III. Outstanding performers among those tested were two alloys containing approximately 35 percent zinc plus other constituents. Their wear rate was very low—about 10 mils per hour—and dwell periods were unusually long—ranging from 1 to 4 hours after a drop of spindle oil was applied to the steel ring. These alloys have been used in refrigerator compressor connecting rods with success, and appear promising for other applications.

Aluminum

Aluminum alloys with characteristics specifically adapted to meet the requirements of heavy duty service are rather new. They offer excellent resistance to corrosion by acidic oils, good load-carrying capacity, fatigue resistance, and thermal conductivity.

Trouble is sometimes encountered, however, with poor embeddability, scoring, seizure, high coefficient of expansion, and the need for shaft hardnesses of 300 Brinell or higher. Many alloys contain about 7 percent tin and 1 percent copper with 1 or 2 percent of silicon or magnesium. The copper is retained in solid solution to provide a moderate increase in strength and hardness. Nickel, silicon and magnesium introduce new phases of greater hardness than the aluminum matrix to improve resistance to scuffing and wear.

The results of preliminary evaluations of aluminum bearings for electric equipment have not been impressive. Thorough tests for possible application in steam turbine bearings indicate that operation with dirty oil causes excessive scoring. In tests for electric clock motors, excessive scoring of the shaft was again encountered. Preliminary compatibility studies for fractional-horsepower motors suggests that ideal operating conditions are required.

Typical compatibility characteristics of several alloys are summarized in Table IV. Although the coefficient of friction and the wear rate were not excessive, the short dwell period indicates relatively poor bearing properties with all the alloys tested under conditions of poor lubrication.

Aluminum-alloy bearings, however, have been used in Germany and elsewhere in Europe in reciprocating engine bearings, steam turbines, electric motors, rolling mills, grinding machines, and a great variety of other applications. Satisfactory results are reported in diesel engines in this country, although particular attention is recommended in the machining of the running surface and to the clearance, lubrication, and thermal expansion.

When the normally bad scoring characteristics of structural types of aluminum are improved by alloying with tin or other elements, such as lead and cadmium, the resulting bearing material usually is quite weak. For this reason, a steel backing frequently is used with a thin layer of bonded aluminum. Such a shell, has also helped to overcome difficulties with the high coefficient of expansion.

Silver Bearings

Most silver bearings are of the three-layer type. The silver is used in its pure form, as electroplated on steel shells from a high-speed cyanide plating bath. It almost always is given a thin —0.0004 to 0.001 in.—coating of lead with approximately 5 percent of indium flashed on and diffused into the lead to avoid corrosion by the lubricating oil.

These bearings have an excellent record in the aircraft industry and are being used in other heavy-duty applications. They have outstanding dimensional and metallurgical uni-

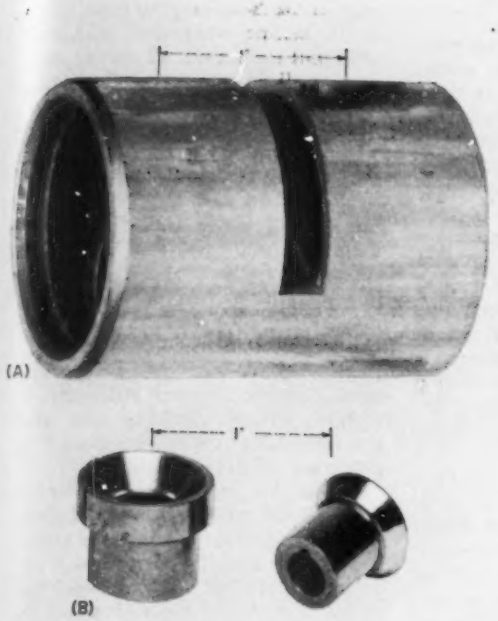

Fig. 8—(A) Typical steel-backed, babbitt-lined bearing for electric motors. (B) Carboloy combination radial-and-thrust bearing for high-speed precision grinders.

Table V—Compatibility Data for Carbon-Graphites*

Material	Wear Rate, in./hr	Coef. of Friction
Best†	0.0002	0.10
Poorest**	0.029**	0.61
Mean	0.0015	0.21

** Some materials shattered almost immediately upon application of load, so no wear rate could be determined. One such sample showed a coefficient of friction of about 0.7.

† Many materials showed wear rates below 0.001 in./hr and coefficients of friction less than 0.20.

* Unhardened 4140 shaft steel; F 3 finish; 250 psi load; 700 ft/min surface speed.

Table VI—Compatibility Data For Plastics*

Material	Dry Wear Rate, in./hr	Dry Coef. of Friction	Oiled Dwell, min
Nylon	1+	0.86	190–1125
Nylon + Graphite	10+	0.64	26
Teflon	0.37	0.17	0
Teflon + Fiberglas	0.003	0.30	27
Textolite** 2001	0.0007	0.18	45
Textolite** 1835	0.008	0.21	0
Textolite** 1841-A	0.30	0.47	55

* Unhardened 4140 shaft steel; F 3 finish; 250 psi load; 700 ft/min surface speed

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formity, fatigue strength, and load-carrying capacity. Their fatigue resistance is so high that, in some cases, the steel backings have been reported to fail before the silver. Their capacity also is outstanding, with only hard bearing materials operating under ideal conditions being able to carry greater loads and its high thermal conductivity has proved helpful in removing heat. Yet, although a lead coating helps to relieve the problem of poor embeddability, silver bearings are still limited to applications where misalignment and dirt are not encountered. Cost is a big disadvantage.

One interesting use of silver is the plating of brass separators in high-speed roller bearings for aircraft gas turbines. These bearings can operate several hours without lubrication before failure occurs. This is attributed to the fact that molten silver will not wet steel and does not readily transfer to the mating steel surfaces. Therefore, welding and seizing of bearing parts are largely avoided. Compatibility tests made with silver-plated brass running against AISI 52100 roller-bearing steel gave a low wear rate, excellent dwell characteristics, and a complete absence of pickup. This suggests that silver plating might be useful in other applications where inadequate lubrication exists.

Porous Bearings

A porous bearing consists of a pressed and sintered metal alloy powder, containing 10 to 40 volume-percent porosity for storing lubricating oil. It is self-lubricating in that a rotating shaft causes a pumping action and also creates frictional heat that aids the flow of oil through the interconnected pores to provide a film between the shaft and the bearing. There is little leakage since the oil is reabsorbed into the bearing by capillary action and by cooling when the shaft stops rotating. Other advantages are (1) bearings can be mass produced, (2) dimensions can be controlled accurately, and (3) cost is low.

Strength and load-carrying capacity of porous bearings vary inversely with the amount of porosity. Bearings containing 88 percent copper, 10 percent tin, and 2 percent graphite have operated successfully at moderate loads with a porosity of 10 to 15 percent. They are not, however, suitable for applications that combine high speed with heavy loads nor should they be used where large impact loads are expected. Fig. 7 gives an indication of the permissible load capacity.

A few compatibility tests have been run on sintered materials, these being, for the most part, without oil impregnation. When run dry or with one drop of oil, these materials behave like cast bronze, with dwell periods ranging from zero to several minutes. When impregnated with oil, a sintered bronze ran for more than five hours without any wear at 250 psi load and 700 fpm surface speed. One oil-impregnated sintered Swedish iron ran for nearly 30 hours at the above conditions, plus another hour and 40 minutes at 500 psi, before wear occurred.

Cemented Carbide

Pressed and sintered compounds composed of particles of tungsten carbide in a matrix of cobalt form a very hard and wear-resistant material with a Rockwell C-scale hardness of 90. The advantages of using this hard and dense material in bearings arise from the high modulus of elasticity and rigidity, plus the relative ease of obtaining a good surface finish. Clearances can be held to a few tenths of a mil.

Tests of carbide journals running with carbide bearings have shown that higher loads and speeds can be used than with any other known materials. In one case, a load of 28,800 psi was applied at 300 rpm on a tur-

bine-oil lubricated bearing before failure by seizure occurred.

Compatibility tests were made with tungsten carbides running against tungsten carbide, chemically dry, at 250 psi load and 700 feet per minute surface speed. No wear occurred, but operation was rough and chattering. Friction values increased with increasing percentages of cobalt in the test pieces, as illustrated below:

Percent Cobalt	Percent Titanium Carbide	Coefficient of Friction
3	0	0.20
6	0	0.38
13	0	0.44
10	8	0.54

The only effects of the tests were an uneven dark coloration of the path on the ring and a polishing of the contacting area of the testpiece. The chattering suggested an intermittent seizing-and-release type of operation, which was possible because the loading spring allowed the test-piece to jump back slightly to free itself without extensive damage. To prove or disprove the once-prevalent belief that tungsten carbide shafts would run satisfactorily in bearings of the same material when perfectly dry, a test was made. Seizure resulted immediately with the application of insignificant loads. Operation at zero load without lubrication required perfect alignment; it then was possible to use air pumped by the rotating shaft as the lubricating medium.

Unfortunately, alignment problems pose a serious drawback to extended use of cemented carbide for bearings because these materials possess neither conformability nor embeddability to compensate for misalignment and dirt. Use is limited also by the high cost of materials and the manufacturing processes required.

Cast Iron

Cast iron has been used occasionally with some success as a bearing material for low-speed applications. The flake graphite present in certain forms is probably the main factor which allows this metal to support a slowly-rotating shaft without seizure or wear. Higher speeds can be used if good lubrication, close alignment, and freedom from dirt are provided as in hermetic refrigerator compressors. Under less favorable conditions, operation is unreliable and seizure may occur suddenly with severe damage to the shaft.

Graphite Materials

The carbon-graphite materials commonly used for brushes in electric motors and generators are now made in a variety of shapes and sizes for use as bearings. With poor lubrication, these bearings are useful because of their inherent lubricity and high wear-resistance.

Their low coefficient of expansion, approximately one-third that of steel, must be considered to avoid loss of clearance when running temperatures are reached. This difficulty can be reduced by using graphite inserts in steel housings. Such a construction is particularly helpful in eliminating difficulties arising from the brittleness of the graphite mixture.

Some grades of graphite are impregnated with a molten metal, such as babbitt, copper, bronze or silver. This is reported to improve strength and heat-dissipating ability, and to permit use where lubrication is impossible because of inaccessibility or extreme temperatures.

Table V is a summary of compatibility tests on more than 50 different grades of carbon-graphite. The results indicate that careful choice of grade should be made because of the large differences encountered. A transition period occurred when the material was started with oil and then allowed to run dry. During this period, the wear products apparently combined with the remaining oil to produce a gummy, sticky surface which caused high friction and high operating temperatures. During the tests, this period was passed safely and conditions reverted to those of dry running. In an actual bearing, however, the expansion of the shaft by the heat could cause seizure. Therefore, those materials probably can be used best perfectly dry wherever a chance exists that only boundary lubrication will be present.

Plastics

Plastics represent a bearing material entirely different from those previously reviewed. Although most plastic bearings have consisted either of phenolic resins, or of nylon, no limit seems to exist in the possible variety of compositions that might be used. General advantages include light weight, good resiliency and easy machinability. Poor thermal conductivity and poor dimensional stability are their drawbacks. The long dwell periods observed in the compatibility test data of Table VI reflect their ease of lubrication.

Many laminated phenolic plastics have found use in recent years as bearings in machines ranging from rolling mills, marine equipment, and heavy steel-mill equipment, to electric clocks and small instruments. Evaluations for their applications in switchgear have indicated that these bearings are (1) outstanding in carrying double the 7000-psi load possible with bronze, (2) stand up very well under severe impact and shock loads because of their high resiliency, (3) have a low coefficient friction, and (4) require less machining then do metal bearings. Ordinary petroleum greases are used as lubricants in this type of application, while water generally is used as a lubricant in steel mills and in marine service. Soluble oils and graphite in the water are reported to give more efficient operation.

Nylon has been used recently in thousands of small bearings for lightly loaded applications in household appliances, toys, bicycles, and various industrial equipment. This material has almost completely replaced wood in such applications and appears to be finding a consistently widening field of use. The compatability test data of Table VI indicate, from the very long oiled dwell periods, that little lubrication is required. Under heavy loads, however, rapid wear and melting of the nylon might be encountered because of its low thermal conductivity.

Teflon is now being used in some applications. It has been of particular interest for use with corrosive fluids, such as might be encountered in the chemical industry. Its present high cost limits use largely to special applications where ordinary bearing materials are unsuitable. Sintered copper impregnated with Teflon has been reported to give a coefficient of friction of only 0.05 at temperatures up to 250 C, and further evaluation should prove most interesting.

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Fig. 1—The heavier yellow and olive drab chromate films are used as a final protective finish for zinc and aluminum die cast parts and stampings.

Chromate Protective Coatings

Non-porous chromate films provide effective, low cost surface protection for non-ferrous metal, both as a final finish and as a base for paint. The chromate finishing process is both economical and easy to control.

C. W. OSTRANDER
Service Mgr., Allied Research Products, Inc.

CHROMATE SURFACE TREATMENTS for metals effectively and economically serve three distinct purposes:

(1) They prevent or reduce metal loss caused by corrosion.

(2) They provide a firm and intimate bond for paint.

(3) They enhance the surface appearance of zinc and cadmium plate.

In addition to their effectiveness in these fields of application the chromates have the added advantages of good electrical conductivity and weldability and can be applied rapidly with simple equipment. The chromate process is economical and easy to control.

These finishes have been successfully applied to zinc, cadmium, copper, brass, bronze, magnesium and, more recently, aluminum.

The chromate protective film, essentially of a complex chromium- chromate nature, is produced by chemical reaction of the chromate solution with the metal surface. It is an integral part of the metal surface, rather than a superimposed film, such as paint. However, the amount of metal that enters into the reaction is extremely slight and dimensional stability of even the most closely machined surfaces is unaffected. The full thickness of the film is estimated to be in the order of 0.00001 inches.

The chromate film is non-crystalline, non-porous and gel-like in structure. It is the freedom from porosity that provides the effective corrosion protection not obtainable by other surface treatments, such as phosphates or organic coatings.

The color of these coatings is dependent upon the thickness of the film. Thin films are transparent. At maximum film thickness the color is yellow, bronze or olive drab, depending upon the base metal and formula used. These

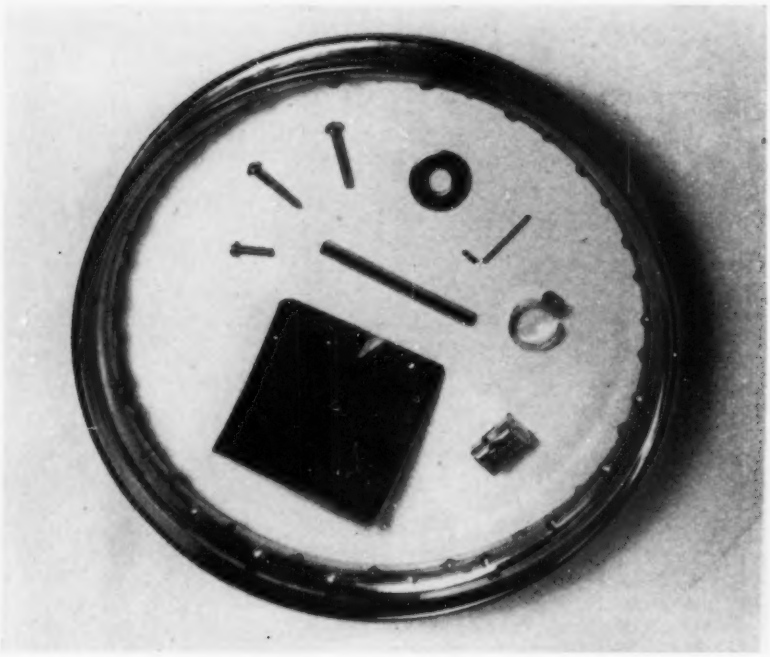


Fig. 2—For plated parts chromates are used to prevent clouding of copper under chrome plate, (the motorcycle rim) and as a protective film over zinc plate. In the case of zinc plating a lacquer is applied over the chromate film to resist abrasion.

natural hues have no appreciable hiding power. Consequently the surface appearance is governed by the condition of the underlying metal surface.

Corrosion Resistance

The factors contributing to the good corrosion resistance of chromate films are their intimacy of contact and their amorphous, non-porous nature. The degree of corrosion resistance is governed by the thickness of the film and the chromate composition. The primary factor is, however, film thickness —the thicker films contributing to greater corrosion resistance.

The chromate films prevent lateral spreading of corrosion because of their sealing action. They also have the characteristic of leaching over into a scratched area to provide renewed protection.

A Base for Paint

The advantages of chromate as a base for paint are: corrosion protection, good adhesion, low absorption, effective surface sealing and good film repair qualities.

The adhesion of paint to the film is effected through molecular attraction, in contrast to the mechanical type bond provided by the crystalline type surface treatments. Molecular bending is characterized by its outstanding intimacy of contact and bonding strength.

The non-porous, amorphous structure of the film prevents any appreciable absorption of paint. Consequently, less paint is required to cover a designated area.

The sealing characteristic of these finishes provides adequate protection against penetration of moisture through the pores of the paint film to the metal surface. It prevents the formation of metallic soaps and reduces peeling on exposure. This sealing quality also provides protection against the lateral spread of corrosion beneath the paint film. The chromate films are equally protective under baked or air dried organic finishes.

Varying degrees of protection can be obtained by manipulation of procedure as well as by variation of film thickness. The life of an ordinary finish is a function of a system of primers and finish coats—the primer coat affording a degree of corrosion resistance. A thin film of chromate could be used to supplant a primer coat and one or more finish coats applied over it. Or, a primer can be applied over a chromate film prior to finish coating. A number of systems of finishing can thus be built up by varying these combinations.

The flexibility of coating selection and finishing system is an added advantage of chromate coatings.

Decorative and Plating Finishes

An interesting development in chromate treatments is their application over zinc plating to produce a finish with the appearance and corrosion resistance of chrome plate. This is accomplished by first depositing a moderately heavy chromate film on the bright zinc plate. The predominantly yellow color of this film is bleached out in a bleach bath without dangerously reducing the film thickness. The remaining red, blue and green hues are then filtered out by applying a coat of clear lacquer on the surface. The finished product is bright and chrome-like in appearance. Good corrosion resistance is provided by the moderately thick chromate film and good abrasion resistance by the lacquer coat.

The bright chromated zinc-plate can be used effectively and economically as a replacement for chrome plate in many applications such as home appliances, automobile trim, jewelry, hardware and refrigerator shelving.

The undesirable clouding of copper plate beneath chrome plate can be prevented by applying a chromate film to the copper prior to chrome plating. The final result is a brighter chrome plate.

Dyed Colors

If colors other than the natural tints are desired on metal parts, without resorting to painting, dyes can be used. Either the yellow or olive drab films, while wet, can be dyed red, blue, green or black. The intensity of the color will vary depending on the original thickness of the chromate film. Dyeing does not effectively hide the surface irregularities of the metal. For a smooth glossy appearance the underdying metal should be polished. The dyes used have satisfactory color fastness for indoor applications but tend to fade in outdoor applications when exposed to direct sunlight.

Functional Properties

Unlike organic or oxide films the chromates have low electrical resistance to direct currents and to low and high frequency alternating currents. This is of considerable advantage in electronics. Protection can be applied to chassis shields, mounting brackets, wave guides and connector plugs without interfering with the electrical characteristics or ground connections. Direct current measurements, see table, indicate that even though the resistance of chromated aluminum is several times that of the clean metal, it is well within the allowable 500,000 michrohm ground resistance.

For high frequency use of aluminum it has been established that no practical difference in the circuit results from the use of chromate as a protective treatment.

The weldability of chromate films permits storage of treated sheet metal and eliminates the necessity for cleaning the sheet prior to welding.

Metals Treated

Zinc—Up to this time the major proportion of chromates has been applied to zinc—primarily die castings but also including sheet, plate and galvanized.

Die cast zinc parts have been effectively protected by the heavier yellow and olive drab chromate films that are used either as a final finish or as a base for paints. The corrosion resistance of the film depends also on the alloy being coated. The higher the copper content the lower the corrosion resistance.

Bright chromate films cannot be satisfactorily applied to die-cast zinc surfaces. To obtain a bright appearance the casting should be zinc plated and treated as mentioned above for bright zinc plate.

Sheet, strip and hot dip galvanized zinc can be chromated to all the aforementioned color effects. The appearance of the underlying surface of the plate or galvanized will show through the chromate films. Sheet and strip can be buffed prior to applying the protective film to enhance the final finish.

Aluminum—The chromate used to protect aluminum forms a somewhat harder film than those on zinc and cadmium. It does not have the hardness or abrasion resistance of an anodized (aluminum oxide) film. It will however resist abrasion of a non-cutting nature and will withstand cold forming operations.

Treatment of aluminum with chromate does not produce embrittlement such as experienced on light gage wire or sheet after anodizing.

The intensity of color and degree of corrosion resistance are affected by alloy content of the aluminum as well as by film thickness. If immersion time is limited to 30 seconds the film generated is transparent and consequently does not affect the surface appearance.

This chromate treatment has proved beneficial on all alloys and forms tested, including work hardening and heat treatable alloys in rolled, drawn, extruded, sand cast, permanent mold cast, and die cast shapes. The number of hours in salt spray to first signs of white corrosion varies in the same order as the inherent resistance of the alloy itself to salt spray attack. In general, the salt spray resistance is inversely proportional to the copper content of the alloy. High copper alloys, 5 to 10 percent copper, show first signs of breakdown in 50 to 200 hours salt spray. Alloys containing copper only as an impurity show first signs of white corrosion in 250 to 1000 hours.

Copper and Copper Alloys—On copper, brass and bronze the chromate film prevents staining and tarnishing and provides good paint adherence and protection. It also can be used to prevent clouding of copper and brass plate. This condition is a common cause for rejection of copper and brass plated parts. There is no appreciable effect of chromate films on the electrical characteristics of copper or on the weldability of copper alloys.

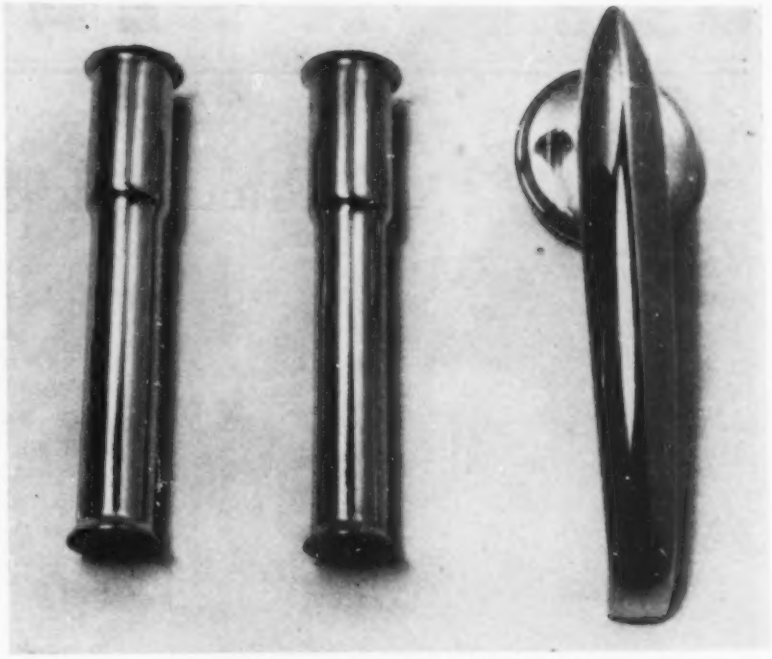


Fig. 3—Chromate treated zinc plate plus a lacquer (door handle) is an effective substitute for chrome plate. The tubes are chrome plated over copper plate. The tube on the right had chromate treatment prior to chrome plating to prevent copper clouding.

Treatment	Electrical Resistance	
	10 psi	100 psi
Cleaned Aluminum	1500 microhms	500 microhms
Aluminum plus Iridite #14	8000 microhms	1900 microhms
Aluminum plus Anodizing	over 88 ohms	over 88 ohms

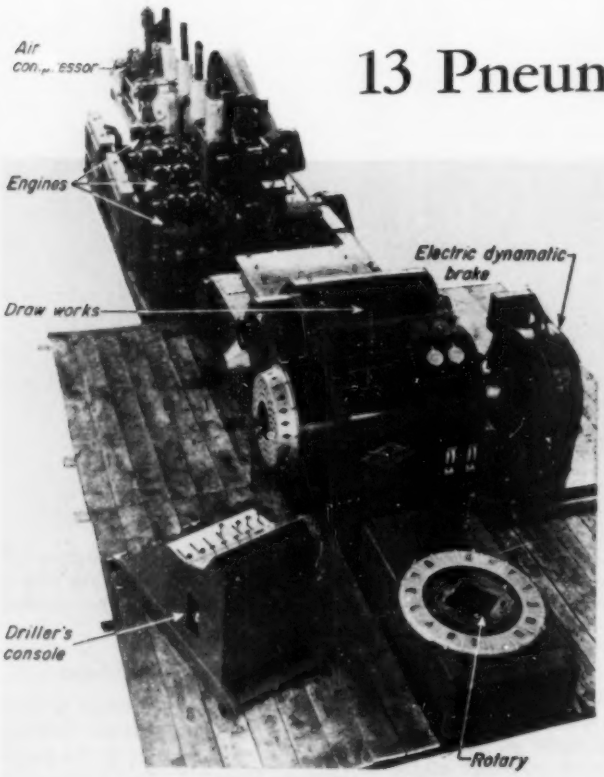
Application Technique

Chromate surface treatment is essentially a short dip process although spraying can be used with the proper chromate formula. For dipping, the immersion time varies roughly from 10 seconds to 2 minutes. In some cases 3 to 5 minute immersion times are used for aluminum. Zinc and cadmium ordinarily operate between 10 and 30 seconds. After dipping, the parts are rinsed and dried by normal methods—a hot rinse and air dry, for instance. If dyed colors are desired it is necessary to introduce a dye tank and subsequent rinse. Or if bleaching is required bleaching tanks must be installed.

All chromate solutions are acidic in nature. To prevent neutralization a good rinse is needed if parts are cleaned in alkaline solutions prior to being chromated.

The composition of the chromate and the immersion time can be varied to suit operating conditions. For instance, if a machine is designed for fixed indexing times formulations can be offered to suit the operation of the machine cycle. In some cases the equipment can be designed in accordance with the requirements for the most effective chromate solution. In any case, however, a knowledge of the end users' requirements is essential to proper selection of chromate bath composition.

13 Pneumatic Systems Control

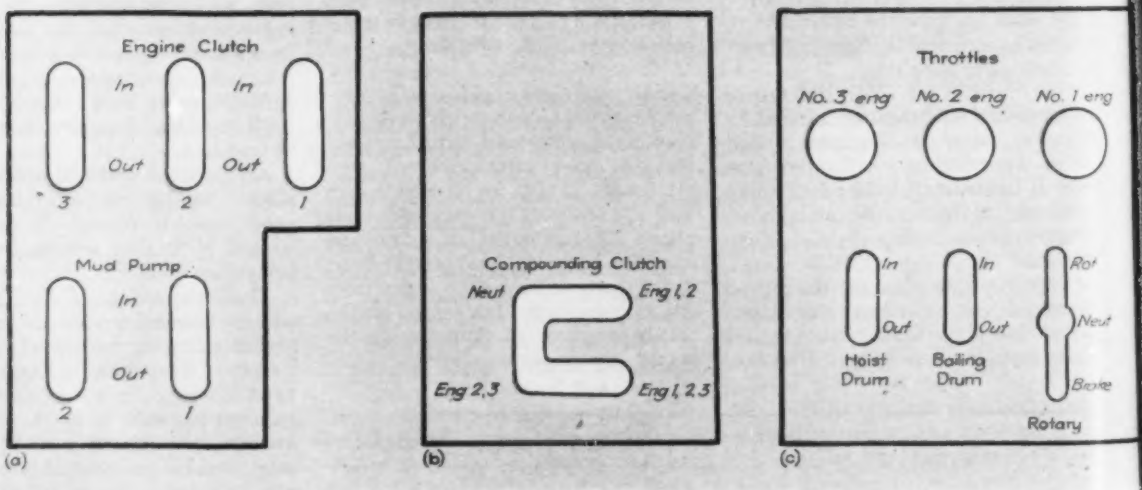


Oil drilling drawworks set up for factory test.

Bringing the controls of 13 different pneumatic systems out to one console permits easy operation of the oil well drilling drawworks built by The Wheland Co., Chattanooga, Tenn., from one remote location. With gages and meters the operator can tell at a glance the running condition of any part of the machine and can control any operation except engine starting from the console through hand and foot controls.

Heart of the drawworks is the pneumatic system by which the operator sitting at the control console can regulate the speeds of the drawworks components. Similarly the drawworks drum, the bailing drum and the high speed rotary (that drives the drill bit) can be clutched in or out.

In this unit, the pneumatic system is designed to control three engines. Usually No. 1 engine drives the drawworks transmission and rotary. Air compressor and pumps are powered by No. 2 engine.



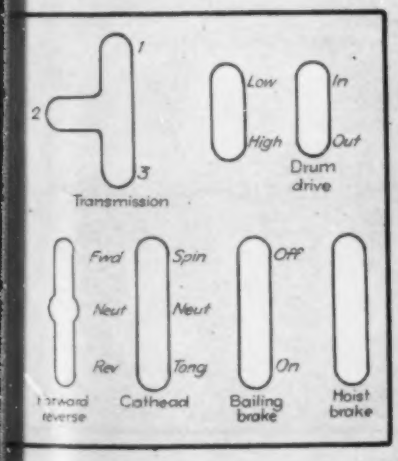
(a) Left-hand control panel contains levers that operate engine clutches and mud pump clutches. (b) Right-hand control panel contains compounding clutch controls that permit using the engines separately or together. All three engines, two engines or one engine can drive the pumps on the drawworks and rotary as required; also any engine may be shut down and the equipment operated by the other engines. (c) Control panel puts controls within

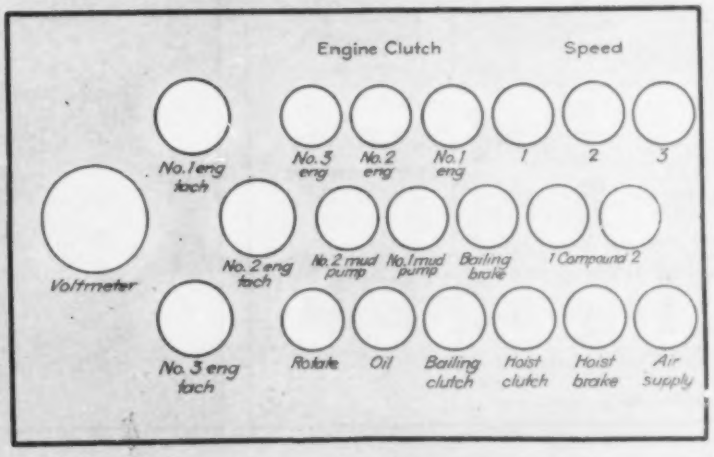
Drawworks from One Movable Console

Controls are designed and interlocked with relays so that it is impossible to jam the transmission. When the operator throws either the reverse lever or a jaw clutch lever, the engaged air clutch in the drawworks transmission automatically opens and the neutral brake sets before the indicated operation can take place.

Main hoist drum drive is through a multiple disc air tube clutch. Other friction drives are Airflex clutches, as are the neutral and rotary brakes. All Airflex units are equipped with quick release valves.

Compounding clutch permits using one, two or three engines to drive each of the components. When the operator throws the lever to engage the engine compounding clutch, the engine throttle actuators are automatically synchronized. This allows the operator to accelerate the engines in unison with the foot pedal or No. 1 engine throttle.

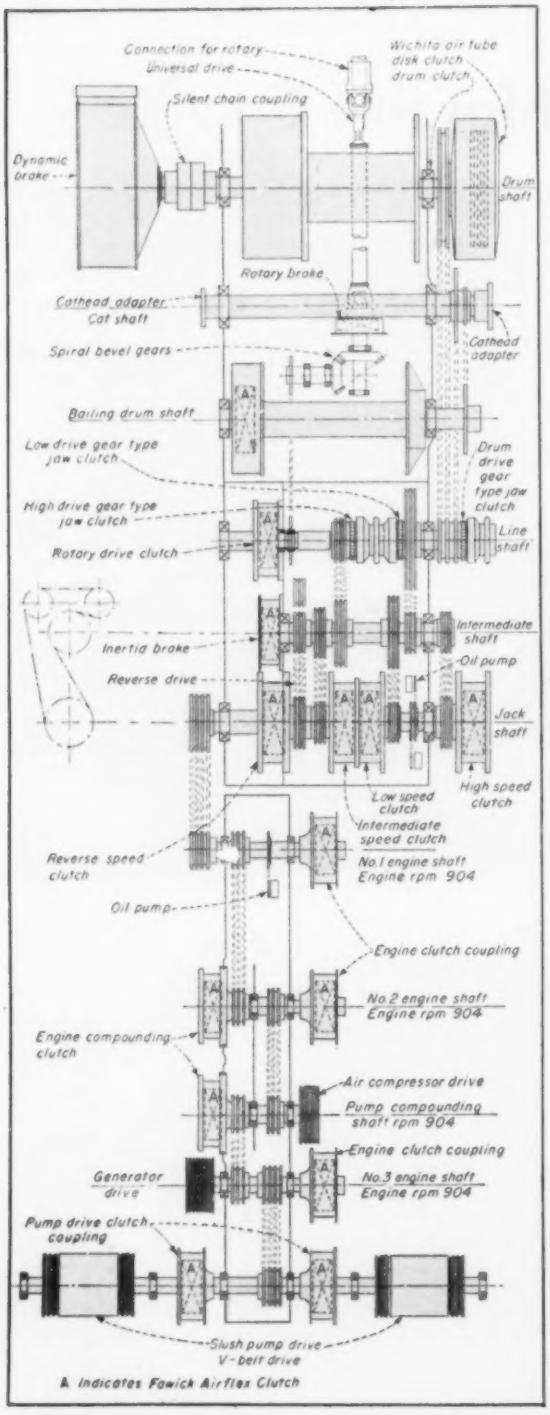




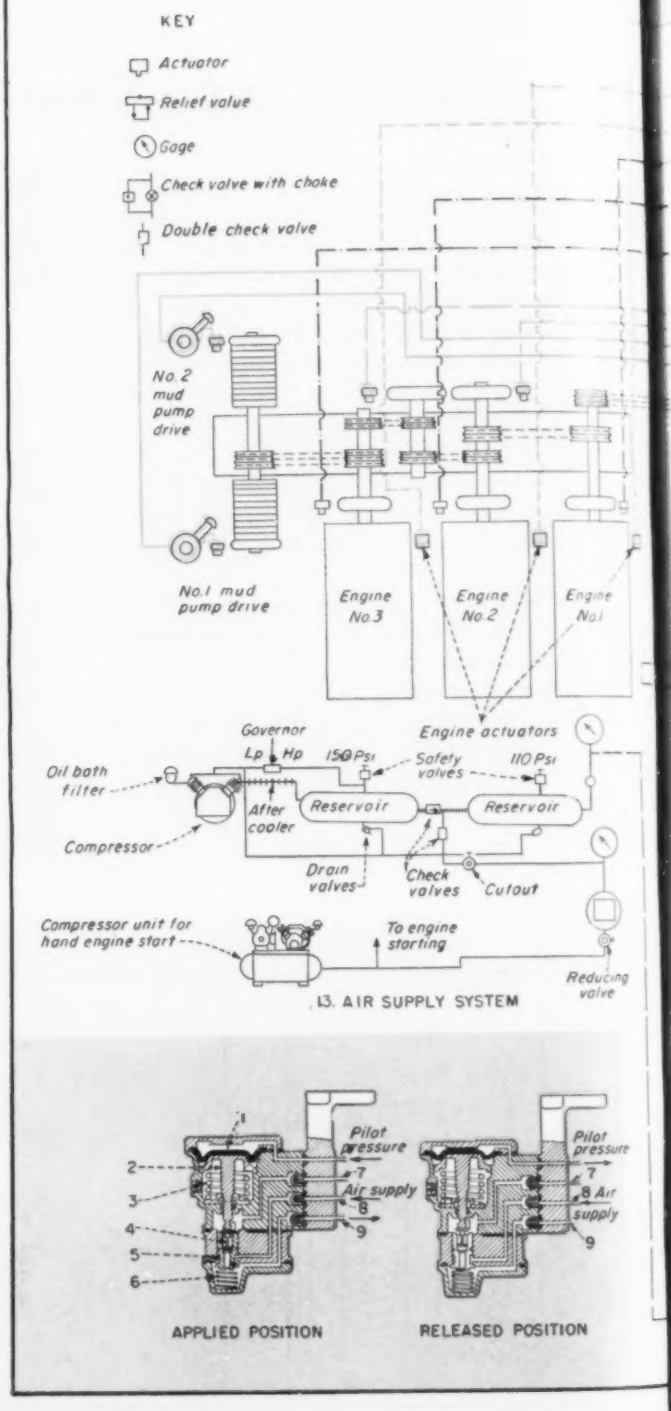
easy reach of operator. Bailing controls (absent in console photograph) are optional equipment. Controls are so designed and interlocked with relays that it is impossible to jam the transmission. (d) Instrument panel shows operator air pressure in main supply and principal clutch lines. Oil pressure gage, engine tachometers and voltmeters complete the picture of the equipment in operation.

(*Continued on next page*)

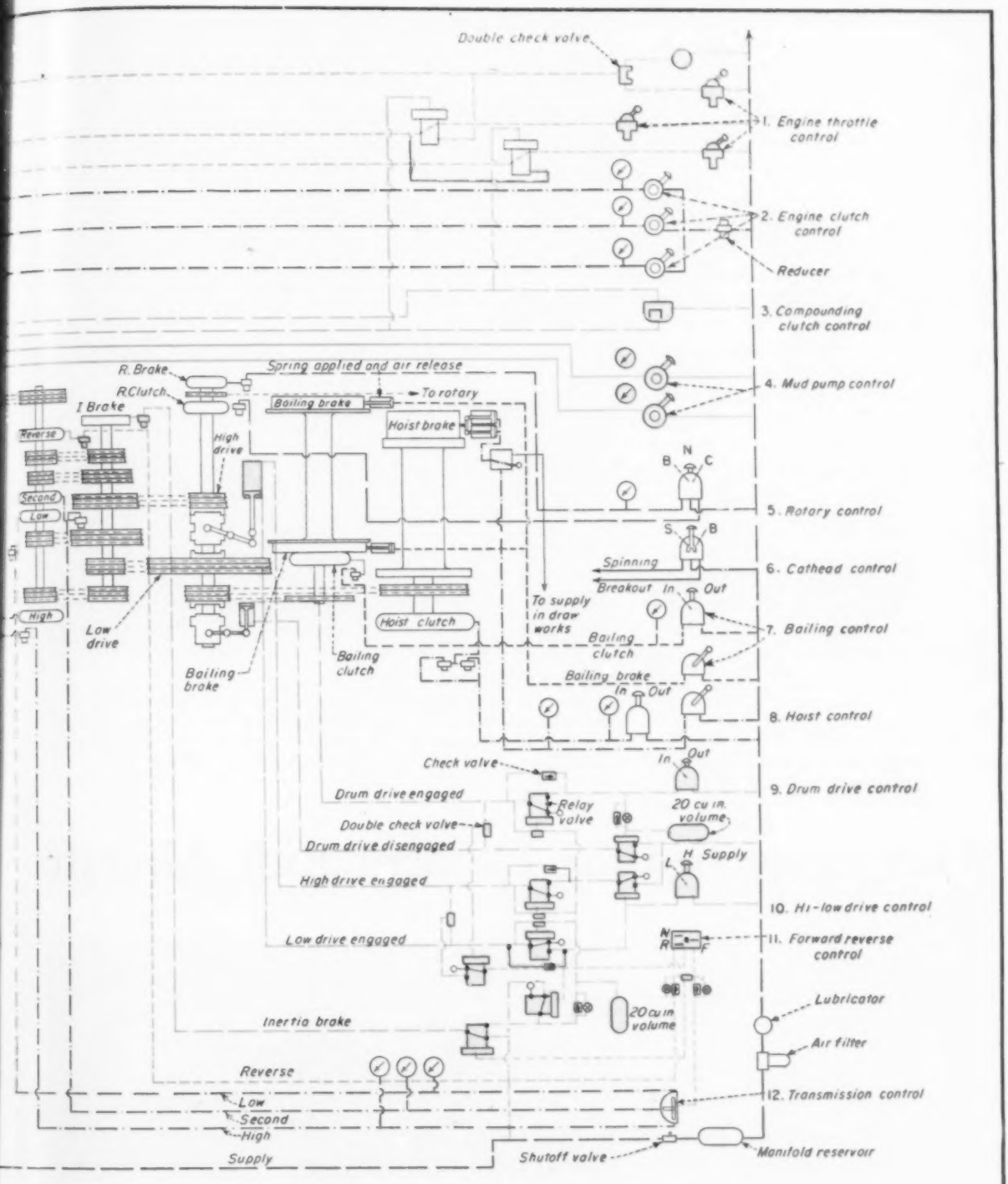
Pneumatic Systems Control Drawworks from One Console (continued)



SCHEMATIC DRAWING of drawworks shows detail of component locations. The spooling drum brakes are simple spring-energized non-kicking band brakes, cooled by circulating water. Dynamic brake is connected flexibly to drum shaft and permits setting of slips without use of the friction brakes under normal operating conditions.



SCHEMATIC DRAWING of pneumatic systems in drawworks. Air compressor driven from No 2 engine shaft supplies air for all systems. Extensive use of pneumatically operated relays interlocks driving controls to prevent jamming of transmissions. All air clutches and the neutral and rotary brakes are equipped with quick release valves. Bailing and spooling drum brakes are spring set and air-released.



WESTINGHOUSE RELAYAIR VALVES (insert) permit interlocking of controls. Pilot pressure enters through passage to chamber above diaphragm (1). When pressure reaches spring setting, diaphragm, and its follower (2) move downward compressing spring (3) and seating exhaust valve (4) on the top of supply valve (5). As downward movement continues, supply valve (5) moves away from its seat, compressing spring (6). The exhaust valve (4) closes exhaust passage (7) while supply passage (8) is connected to delivery passage (9). When pilot pressure is vented, spring (3) returns diaphragm follower (2) and exhaust valve (4) to their upper positions, unseating the exhaust valve. Spring (6) then seats supply valve (5) and closes supply passage (8) so valve exhausts.

Thermistor Sensing Element Rids Aircraft

An aircraft fire detection system that will not give false alarms but will still give quick positive indication of a real fire has been developed by Walter Kidde and Company, Inc., Belleville, New Jersey. In the past, false alarms have been the main objection to most systems because they weakened the pilot's faith in the system.

Kidde's answer to the problem is the fixed-temperature, continuous ceramic sensing unit pictured here. The sensing element consists of two small Inconel conductor wires surrounded by an insulating thermistor ceramic. At normal temperatures, the ceramic offers high resistance to the flow of current between the wires. But when subjected to the high temperature of a fire, the resistance of the ceramic drops rapidly and permits a flow of current between the two wires.

The monitoring control unit receives this current and activates an alarm when a predetermined temperature is reached. When the temperature returns to normal, the resistance of the ceramic is restored and the alarm shuts off indicating the fire is out.

These design features prevent false alarms:

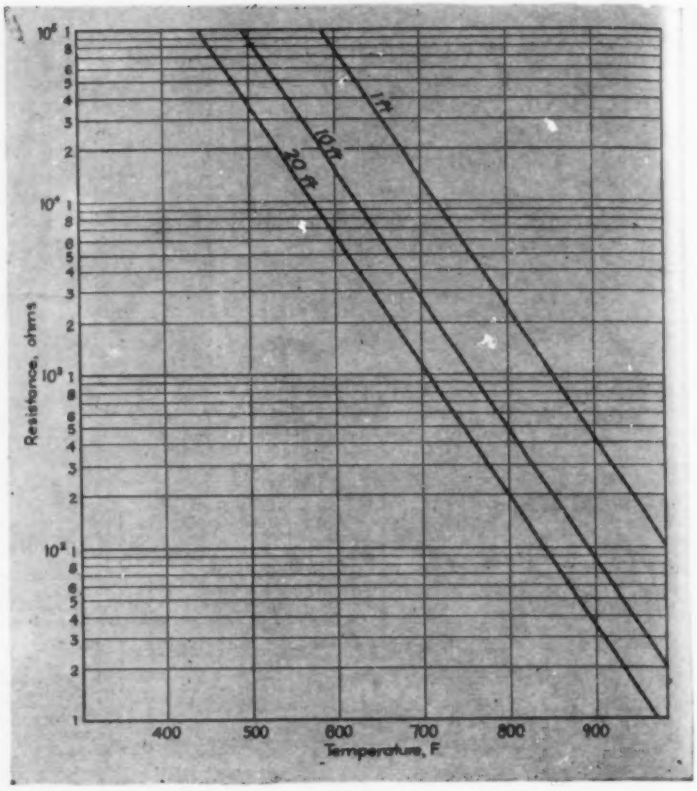
1. Completely shielded circuit prevents an alarm signal caused by inductance with other electrical wiring. It also prevents possible radio interference.

2. Hermetically-sealed sensing element eliminates possible short circuits caused by moisture.

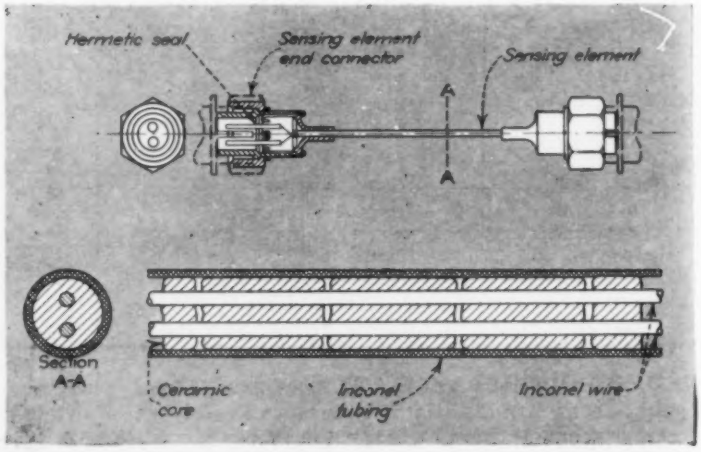
3. There are no moving parts like relays to stick or malfunction.

4. AN electrical connectors, sealed type with coupling nut, prevent loose contacts and afford vibration-proof connections.

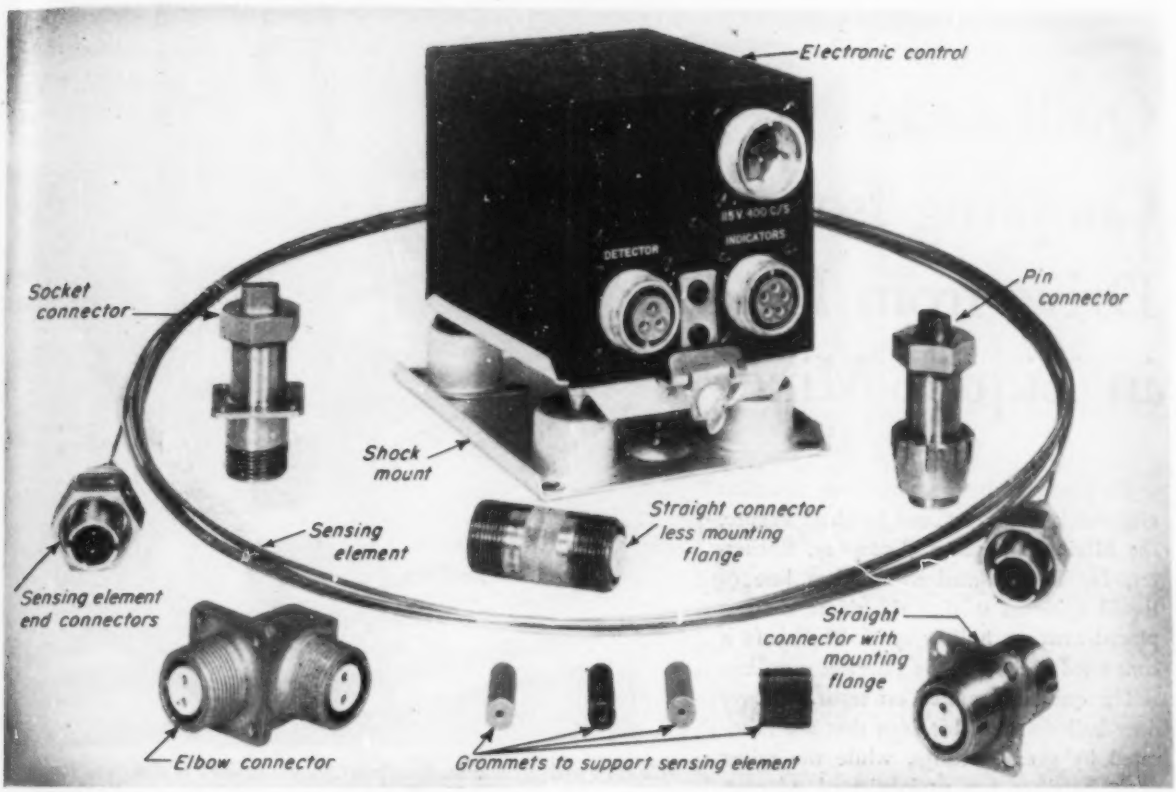
Because the sensing element is in wire form, it may be wrapped around a power plant to permit detection of fires formerly not reported by unit detectors because of stratification of the flame. This entire system is fireproof and cannot be knocked out of service by a fire.



CHARACTERISTICS of sensing element. System can be set to give alarm at varying temperature. If system is set to give alarm when ceramic resistance is 10^4 ohms: a temperature of 720 F on one foot of element will give an alarm; a temperature of 625 F on 10 ft; or a temperature of 575 F on 20 ft of the element will give an alarm.

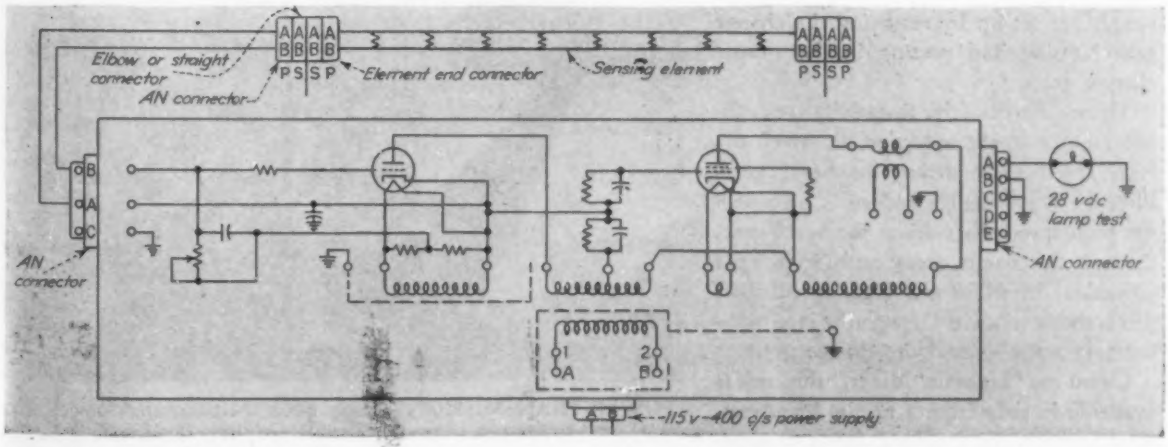


FIRE SENSING ELEMENT. Thermistor ceramic is extruded around conductors like spaghetti, and an additive causes it to form bead-like pieces when fused. Ceramic is bonded chemically and physically to wire.



COMPONENTS of Kidde continuous aircraft fire detection system. Heavy connectors are used to provide fire resistance and shock resistance. Elbow and straight connectors carry system through fire walls and bulkheads. Socket and pin connection carry 2-conductor fire zone wire in braided stainless steel shield to provide flexibility at points where there are large magnitude vibrations. Outside tubing of inconel on sensing element makes unit ductile and corrosion resistant even after exposure to high temperature. Electronic control box is mounted on vibration mounts.

Fire Detection System of False Alarms



SCHEMATIC CIRCUIT DIAGRAM. Circuit is shielded to prevent radio-interference and false alarms caused by inductance. An alternate sensing circuit is used in military applications where sensing element is subject to gun fire. Army-Navy connectors are used to prevent loose contacts and afford vibration-proof connections.

Quill and Coupling Isolate Drive from Load in Liquid Mixer

To protect drive gearing from vibration and shock loading caused by shaft flexure, the Mixing Equipment Company, Rochester, N. Y., designed a complete line of liquid agitators so that the mixer shaft is placed inside a hollow quill. The shaft is connected to the quill by a flexible coupling.

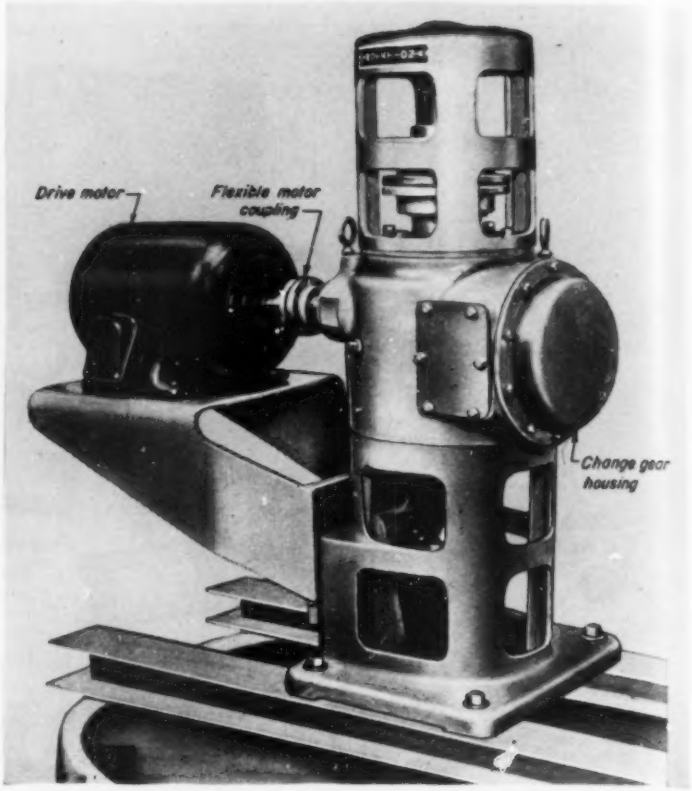
The quill is mounted on separate heavy duty ball or roller bearings that are lubricated by grease fittings, while the mixer shaft bearings are prelubricated adapter-type ball bearings with synthetic rubber seals.

Since the mixer shaft is supported independently, different shaft diameters, lengths and materials can be used without changing the drive. The shaft can be removed upward or downward.

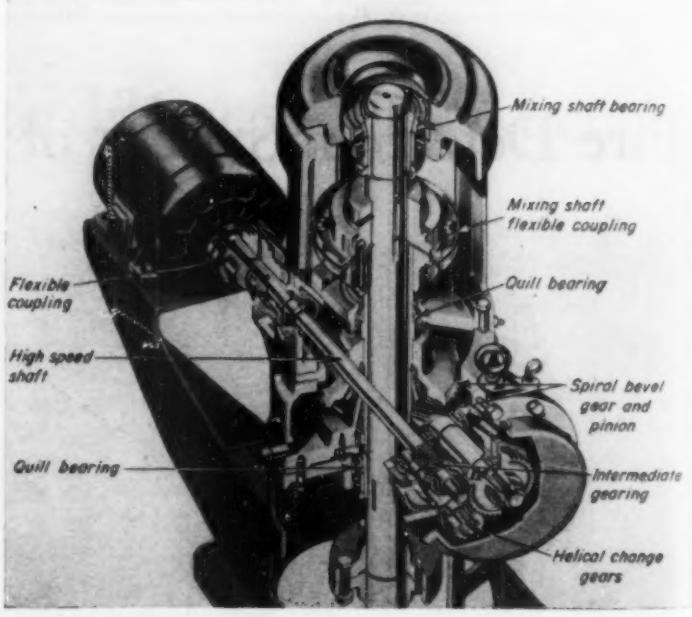
Up to sixteen different mixing speeds are possible with the unit and speeds can be changed without disassembling the entire mixer or removing it from the tank. Desired speeds are set up by removing the change gear housing and putting in the proper change gears.

Three different drive assemblies are available: (1) a single reduction, in which the high speed shaft drives the bevel gears directly; (2) a double reduction, in which the high speed shaft drives the bevel gears through the change gears; and (3) a triple reduction, in which the high speed shaft drives the bevel gears through the intermediate gear assembly and the change gears.

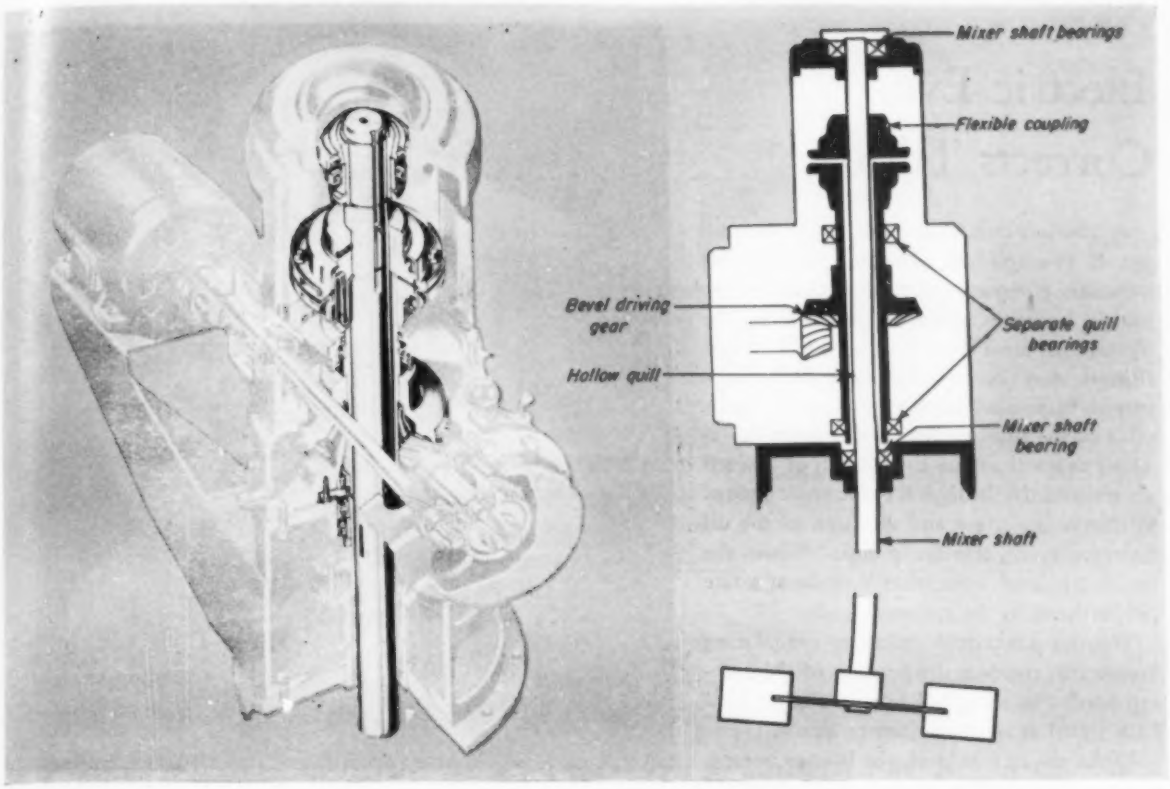
Called the "Lightnin' Mixer," this unit is available in sizes from 1 to 500 hp. Accessories convert the standard drives to open-tank, closed-tank or bottom-entering mixers in a few minutes.



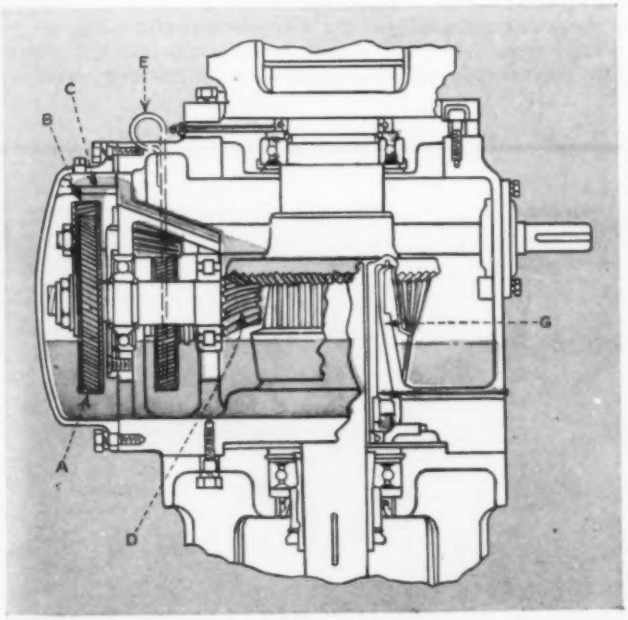
MIXER (with accessories for open tank operation) is designed for fluid mixing. 16 standard speeds are built into the drive and the unit is converted from one speed to another by a simple gear change.



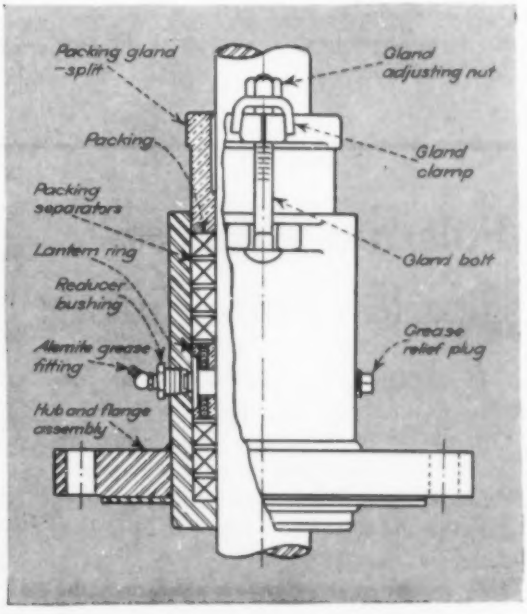
POWER TRANSMISSION. High speed shaft transmits power from motor to change gears through flexible coupling for double reduction as above, or through intermediate gear assembly for triple reduction. Change gear drives bevel pinion that meshes with the quill-driving bevel gear. Flexible coupling connects hollow quill and mixer shaft



CUTAWAY VIEW shows detail of flex-protected construction for standard drive. Flexure is exaggerated in schematic diagram (right) that shows how the mixer shaft is coupled to the hollow quill. Flexible coupling isolates drive from load to protect gearing. Mixer shaft bearings are pre-lubricated adapter-type ball bearings.



GEAR LUBRICATION. Large change gear (A) lubricates pinion (B) and pumps oil to reservoir (C). Oil flows by gravity to bevel gear and pinion (D). Bayonet type oil level gage (E) gives position indication of oil level. Oil dam (G) is leakproof, extending well above oil level.



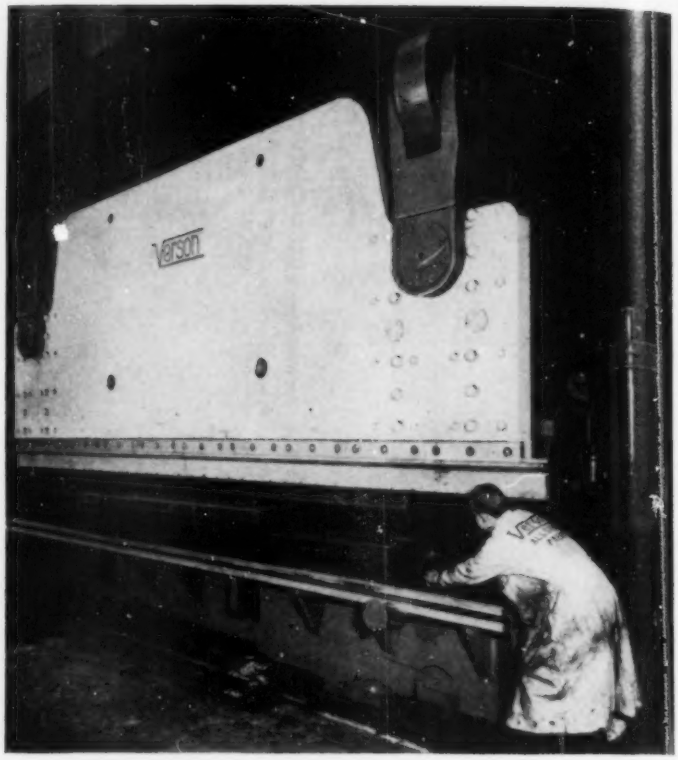
STUFFING BOX for closed-tank assembly is designed for pressures from full vacuum to 150 psi, and temperatures of from 0 to 300 F. Drawing shows the seven packing rings and packing separators that distribute gland pressure over the packing face.

Electric Eye Corrects Tilting

A photoelectric cell, controlling the output of an amplidyne generator that supplies a transfer pump motor, corrects tilting of the ram in hydraulic press brakes made by the Version All-Steel Press Company, of Chicago, Illinois. Any tilt of the ram raises or lowers a barrier suspended between the photoelectric cell and the light source. And barrier movements as small as one thousandth of an inch are transmitted through the electronic control to change the speed and direction of the oil flow from the transfer pump. When the ram is not level, correction is made at a rate proportional to the amount of tilt.

Transfer pump drive makes up a regulating system that controls the position of the moving barrier so as to balance an electric feed back signal against a reference signal.

When the ram is level, the barrier is centered in the light path, so that the error signal is zero, and the transfer pump drive is stationary. If the barrier is moved, light transmitted to the phototube is increased or decreased, and the feedback signal is increased or decreased. This produces an error signal which causes the transfer pump drive to correct the non-level condition.

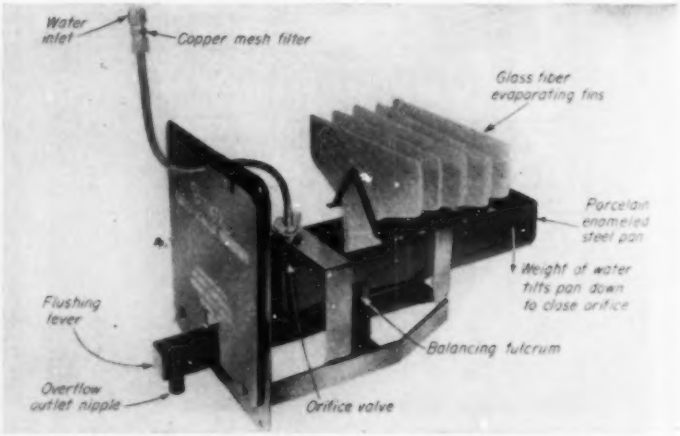


HYDRAULIC CYLINDERS, supplied by individual pumps, drive each side of the ram on this 1,000 ton press. Controlling the level during ram travel is a major problem because of inequalities in the pumps as a result of slip in the pistons and unequal pump loading. Transfer pump can take oil from either line and put it in the other line to equalize these differences and keep the ram level. Transfer pump drive and controls make up a regulating system that supplies a reference signal. The ram moves the barrier to produce a signal from the photoelectric cell that is opposite to the reference signal.

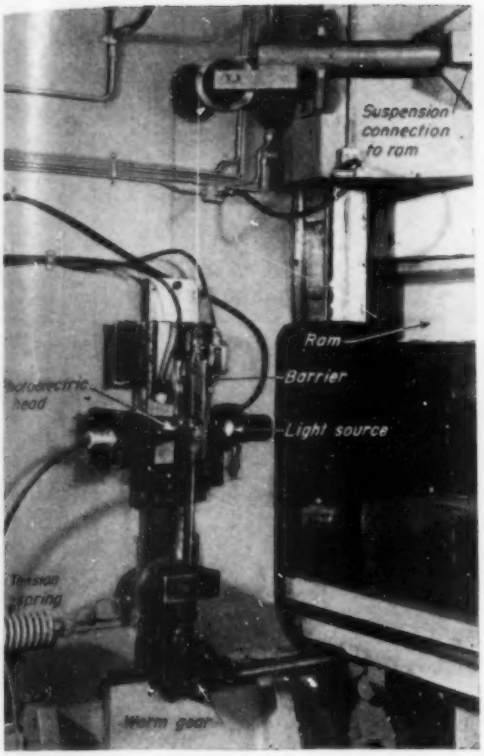
Fulcrum Balances Floatless Humidifier

In redesigning a humidifier for home furnaces to save brass and copper, the Bettinger Corporation of Waltham, Mass. came up with a porcelain enameled steel unit that is automatic and does away with the float chamber and float valve required in former designs.

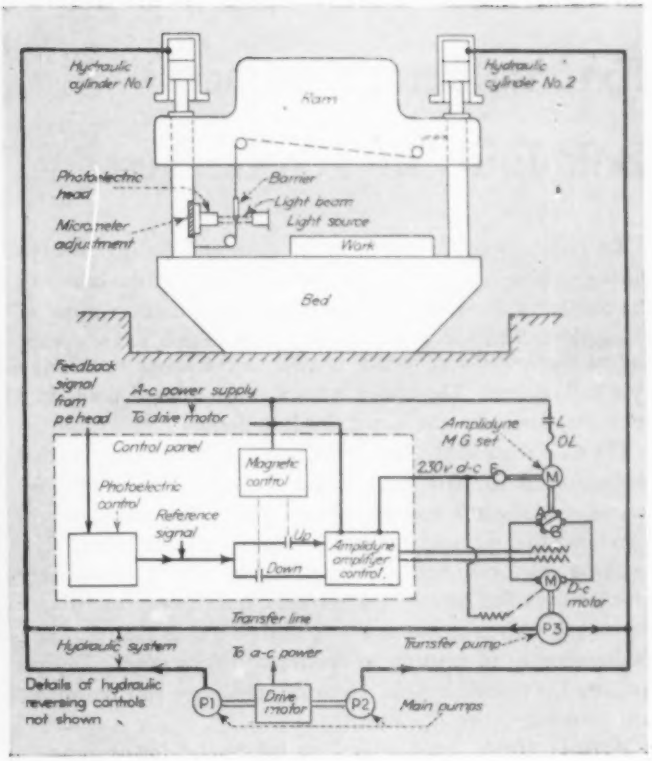
By mounting the tank on a fulcrum, the weight of the water is used to tilt the tank, which then closes the oversized-orifice intake valve to shut off the flow. Operation is not affected by changes in line water pressure or valve clogging.



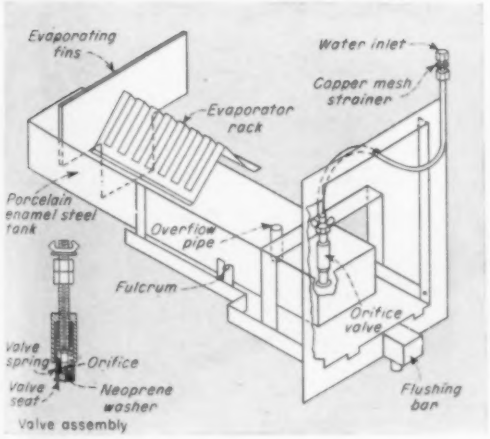
PORCELAIN ENAMELED-STEEL replaces copper in new floatless humidifier. Resistance to heat, moisture, corrosion and rust makes it a satisfactory substitute material. Elimination of float chamber and valve reduces amount of brass in device.



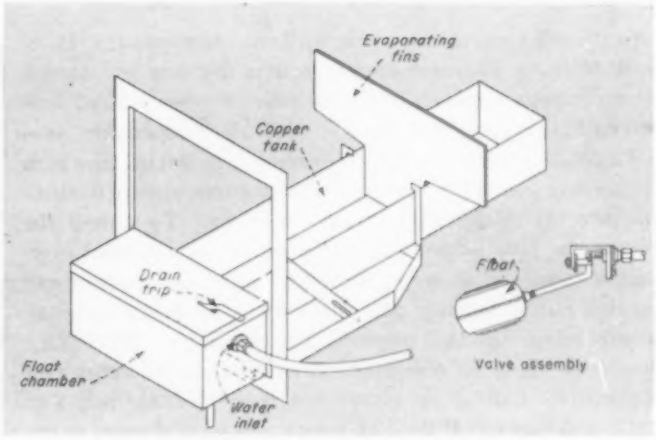
PHOTOELECTRIC DEVICE. Barrier suspension is such that its vertical position is unchanged by vertical movement of the ram, but is affected by the tilt of the ram. Ends of the suspension system are connected to stationary members of the press. Coil spring maintains tension on the suspension but allows necessary change in length and movement of the barrier during tilt. Predetermined tilt is set up by level adjustment.



SCHEMATIC SKETCH OF CONTROLS. Feedback signal from photoelectric cell is balanced with reference signal from transfer pump drive. Any unbalance makes up an error signal that is carried to the amplidyne amplifier control to regulate the direction and speed of amplidyne motor generator set and transfer pump motor. System is always attempting to reduce the error signal to zero by producing a feedback signal equal and opposite to the reference signal. When error signal is reduced to zero transfer pump drive is stationary.



NEW DESIGN. Entering water passes through orifice valve held open by spring pressure. Water fills the tank balanced at the fulcrum. Weight of water in long end tilts tank and closes orifice.



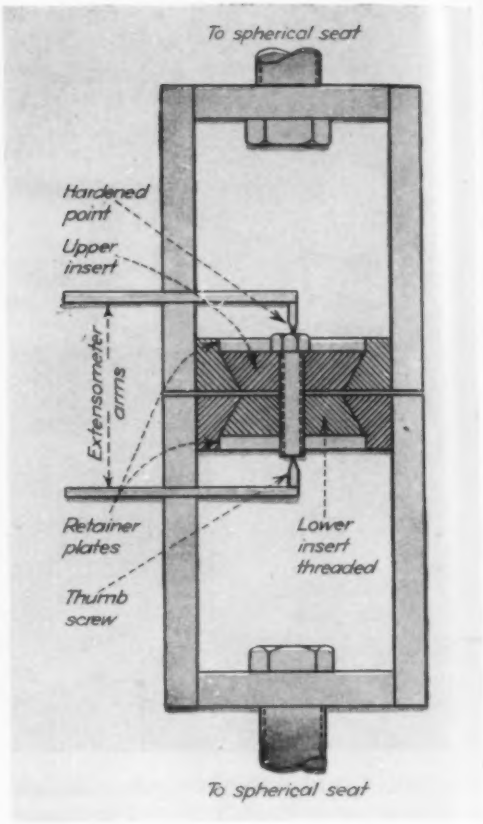
OLD DESIGN. Water enters into float chamber and as it fills chamber, it passes through connecting nipple into copper tank. Rising water raises float shutting water supply off. Float valve is subject to clogging and leaks if inlet water pressure is too high.

Extensometer Contacts Bolt Ends in Tensile Test

To avoid errors from shifting of grips and seating of bolts during tension tests, a new extensometer contacts the center of the test bolt's ends to make direct and exact measurements of elongation. The lower contact is a long thumb screw on the end of the lower arm, which is held to the lower test fixture by a coil spring. The upper contact is a hardened point in a yoke that straddles the upper loading frame.

The measuring device uses a variable core transformer so that elongation of the test piece moves the core and changes the reactance of the unit and its output. This unbalances a recording circuit that includes another variable core transformer. The resulting electrical impulse is amplified to drive a servo motor which moves the core of the recorder transformer to balance the electrical circuit; and at the same time moves the recording mechanisms in proportion to specimen deformation. During test, the lower arm is held relatively stationary and the upper arm pivots to move the core.

Movable pivots are provided on upper and lower arms to permit unrestrained movement of the core and to permit arm adjustment when setting up the test.

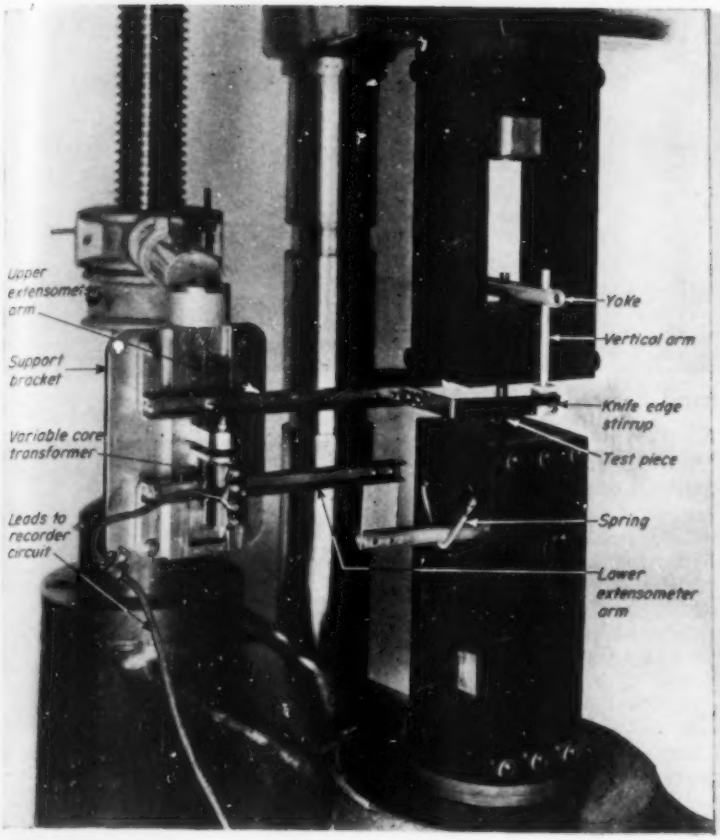


Magnetic Starter Responds to Refrigeration Temperatures

In the sub-zero cabinets made by Revco, Incorporated, Deerfield, Mich., a magnetic starter protects the first and second stage compressor motors, shuts the unit off when desired temperature is reached, and starts it when the temperature rises.

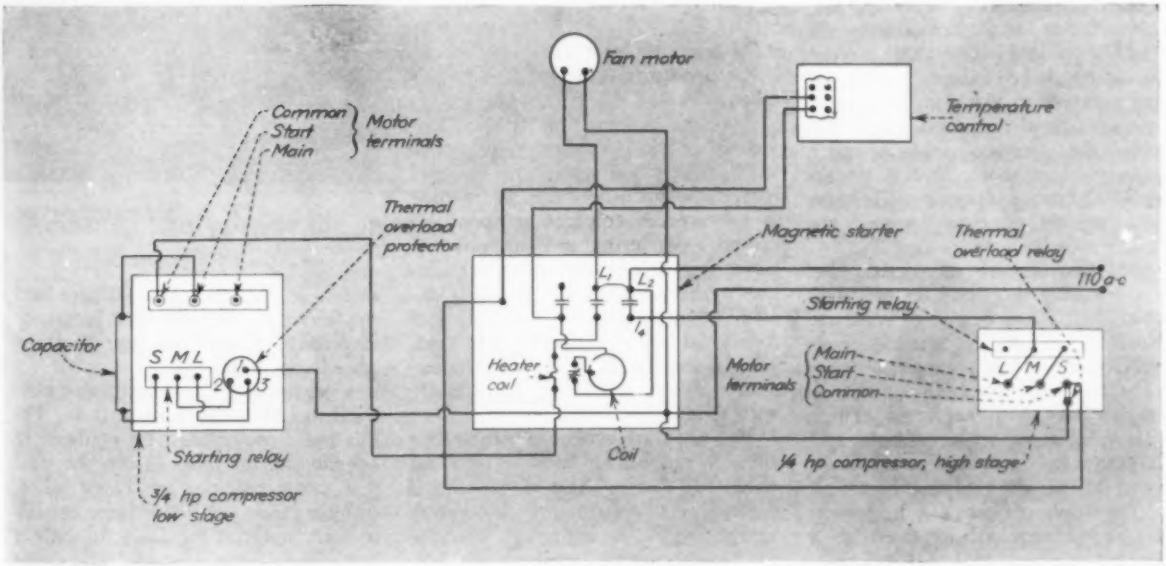
To do this, Revco wired the temperature control in series with the holding coil of the starter, so that the temperature monitor can turn the refrigeration system on or off. To protect the motors, the ¼ hp second stage compressor motor thermal overload is connected in series with the temperature control and the line starter holding coil, while the ¾ hp first stage compressor motor thermal overload is connected to the voltage supply. If the ¼ hp compressor is overloaded, the entire unit is shut off; if the ¾ hp compressor is overloaded, only that machine is shut off. If the ¾ hp compressor were allowed to run when the ¼ hp unit had tripped out, the suction pressure of the ¼ hp unit would be equal to the head or condenser pressure of the system and at high ambient temperatures the second stage unit could not be restarted.

REVCO cold chest refrigeration system has two hermetically sealed compressor units. One magnetic starter protects both these motors as well as turning the unit on and off in response to temperature control.



NEW extensometer contacts bolt ends during tensile tests. Retainer plates hide contact points in cut at left. Upper extensometer arm rests on two knife-edge strips of vertical bar and yoke assembly. Vertical arms are adjustable to cover a range of bolt sizes. Extensometer arms are parallel when test begins. These units will operate with loading frames of 50,000 lb capacity to test bolts up to ¾ in. in size. The extensometer has magnifications of 12.5, 25 and 50 to 1.

HARDENED tapered inserts fitted in a box-like fixture hold the specimen during test. The upper insert has a clearance hole for the bolt and the lower one is threaded. Load is applied through the threaded insert. Retainer plates keep the inserts and bolts from jumping out at fracture. Developed by the International Harvester Company, Chicago, Ill., the units are being built by the Baldwin-Lima-Hamilton Corporation, Philadelphia, Penna.



WIRING DIAGRAM shows how temperature control is wired in series with holding coil of magnetic starter. Starter also controls the two compressor motors: ¼ hp motor thermal overload is connected in series with the starter holding coil so that if it is overloaded, both compressors are stopped. A ¾ hp motor thermal overload is connected to the voltage supply. When the ¼ hp motor is overloaded, the entire machine is shut off, but when ¾ hp thermal overload trips, only that unit is shut off. If holding coil is overloaded, both motors are stopped.

Some catalog or hand book data . . . . . .

The Federal Machine & Welder Co.

Or a torque wrench . . . . . .

Or a laboratory-type

F. H. HOLMAN
L. H. BERKLEY
Master Electric Company

SELECTING MOTOR SIZE is one of the steps involved in the design of motor-driven machines. Unfortunately, many designers feel obliged to choose between elaborate theoretical analysis and guesswork. And, the latter approach is selected much too frequently. These designers overlook at least four other methods of determining motor rating that span the gap between theory and guesswork.

Poor estimates result in the choice of incorrect ratings. These ratings are most often on the safe side so the motor is actually too large for the job. The penalties are high first cost, excessive space requirements, low power factor and inefficiency. It should be pointed out here that present day motors have sufficient safety or service factors so that additional margins are usually undesirable. Of course, the alternate result of poor guesswork is a motor that is undersized. Decreased operating life, frequent stalling or even burnout are possible effects.

Such troubles are unnecessary because motor ratings can be predetermined with a fair degree of accuracy. Several techniques are available, each applicable to certain problems.

1. Calculation from existing data is a method frequently neglected. There exists in the handbooks, textbooks, and manufacturers' catalogs, a wealth of information that simplifies mathematical determination of motor horsepower. The rating required to motorize a standard machine tool, for example, can be obtained from any one of several handbooks. The power required for a certain metal-cuting operation can likewise be determined from tabulated information. Data on screw efficiencies, gear efficiencies, etc. facilitate calculation of horsepower required for roll-adjusting and traversing motors, etc. Experience with similar machines of another size is invaluable.

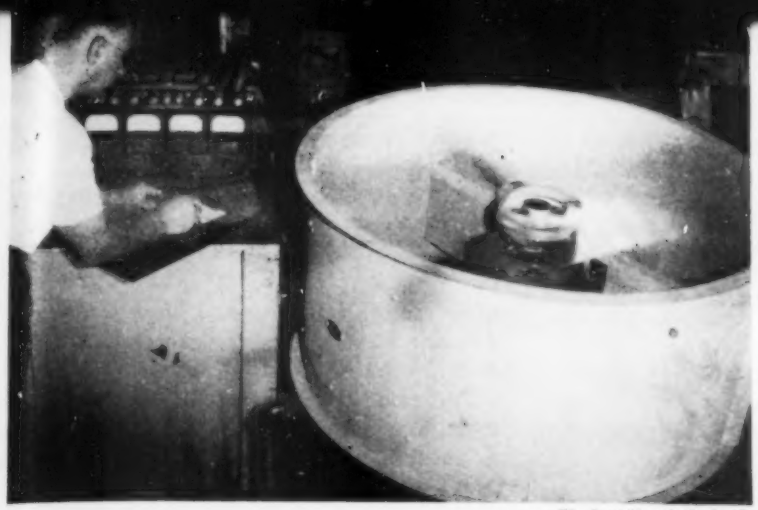
But calculation of motor horsepower is impractical in many cases. The desired data may not be available. The machine may be so complicated as to make the procedures lengthy, time-consuming and expensive.

2. A simple torque test can provide a quick, accurate answer if a prototype or production model of the machine is available. To perform the test a torque wrench or a long lever carrying a spring scale is fastened to the drive shaft of the equipment. The torque required to rotate the load by hand is read directly on the scale or easily calculated by multiplying the reading by the length of the torque arm. The scale and the lever must, of course, be perpendicular when the reading is taken.

This test has its limitations. Obviously it is inapplicable where torque varies greatly with speed. It is limited to applications where the load torque is substantially constant as speed increases. Conveyors and machine-tool traversing drives are suitable examples. Although theoretically it is desirable to manually rotate the shaft at its normal operating speed, such is not always practical. But this is not necessary if torque varies only slightly with speed.

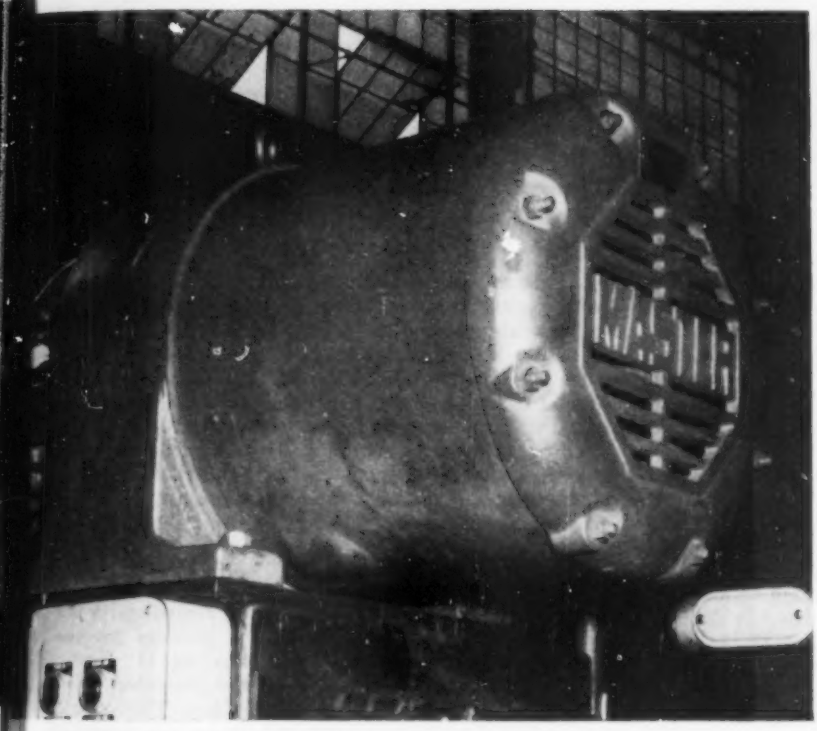
This test is particularly advantageous since it can be run without the aid of a trial motor. Also it provides a method for determining breakaway torque, which is important where a mechanical system tends to "freeze up" while sitting idle overnight. It is sometimes more desirable to mount a pulley on the driven shaft, fasten a rope to the outer edge of the pulley, and gradually add weight until the shaft just starts to rotate. Where field conditions may impose dirt, grease, or ice on the mechanism, this must be considered.

3. A steady running test using electrical meters is the third method. For this test a motor must be available to operate the machine during the time that meter readings are being taken. In most cases, any motor large enough to start and run the load for only a few minutes is satisfactory. The motor is coupled to the shaft of the machine and the steady running power input measured, preferably with a wattmeter. This reading, together with the motor efficiency, can be translated into



The Burt Manufacturing Co.

Or a few electric motors . . . . . .



thermometer can provide the answer to . . . . . .

How Big A Motor?

shaft horsepower. This test is, of course, applicable even where load torque varies greatly with speed. Pumps and fans are examples of equipment to which this method can be applied.

In some cases, the load may vary over a period of time. This complicates motor selection because the problem of duty cycle must be considered.

The motor rating required to drive a machine with varying duty cycle can be determined from a curve of instantaneous horsepower vs time. The points on this curve are obtained in a running test by taking periodic readings of input watts or amperes. Or, still more accurate results are possible if a recording wattmeter or ammeter is used. These devices automatically prepare the curve of watts or amperes vs time. It is a simple matter to convert such data into a plot showing input horsepower directly. The rms average value of the ordinate of this curve is the motor rating needed to power the load without overheating.

4. Use of the three methods discussed above presumes that the motor runs in one direction and with a fairly constant load. Neither is alone applicable where the motor must start or plug-reverse frequently or where load varies greatly. In such cases, final determination of horsepower rating can be made only by a heat run to measure the temperature rise of the motor. Here a motor that is similar to the motor ultimately intended to run the machine must be used. Obviously, if the application clearly indicated a NEMA Design-D, high-torque, high-slip motor, a heat run on an available Design-B motor, although otherwise identical in all other specifications, would not give conclusive information. Hence, the heat run is usually made as a test of a previously calculated rating. Such calculations consist of dividing the overall duty cycle into its various phases. Each of these phases —accelerating, steady-run, plug-reversal, etc.—is in turn examined to determine its rms horsepower. When all of the individual rms values are obtained, then the overall rms horsepower is determined. A motor providing such horsepower can then be subjected to a heat run.

If the observed temperature rise is only 20 C on a 40 C motor, the machine is, of course, overmotored. However, if the temperature rise is 60 C, a larger rating is clearly required.

Temperatures in a heat run are commonly measured by means of a laboratory-type thermometer. This is "puttied" to the portion of the exposed motor frame that will experience the highest measurable temperature rise. This method is satisfactory for the majority of tests, although errors are possible because of improper location or inaccuracies of the thermometer. If more precise results are needed, the temperature rise can be determined by measuring the resistance of the motor winding before and after the run, preferably by an accurate bridge. Then, knowing the temperature coefficient of resistance, the exact temperature rise of the copper conductor can be calculated.

13 Ways to Use Magnetic Amplifiers

H. D. JAMES
Consulting Engineer

HOW A MAGNETIC AMPLIFIER OPERATES

A simple form of the self-saturating magnetic amplifier appears in the sketch. It consists of a single iron core carrying two separate coils. One is the control coil, consuming small quantities of d-c electrical power. This is connected to a control device, such as a switch or meter.

The second coil is connected in the a-c load line. It acts as a valve, regulating the current available to the load, which may be a motor. With this device, small currents in the primary coil control large currents in the secondary coil. Hence, the term "magnetic amplifier."

Impedance changes are responsible for the valve-like action of the load coil. The impedance of the coil is a function of the amount of flux that the load current can set up through its windings. Total flux is, in turn, proportional to the satura-

1 MOTOR SPEED CONTROL. The magnetic amplifier offers a convenient means of providing adjustable voltages for changing the speed of a d-c motor. Voltage at motor terminals, Fig. 1, is supplied from the d-c side of a static rectifier. The latter receives a-c power through the load coils of a magnetic amplifier. The impedance of the amplifier is controlled by a d-c coil that draws rectified power from the a-c system through a rheostat.

By resetting the rheostat, the current in the control coil is increased, causing greater saturation of the iron core. The resulting drop in the impedance of the amplifier load coils raises the voltage across the motor terminals. This brings about a proportionately greater motor speed.

An opposite effect on motor speed is caused by lowering the current in the control coil. The impedance in the load coil is increased and reduces the net voltage available across the motor terminals.

The d-c power in the field coils of the motor is supplied by a separate rectifier. A resistor, not shown, can be put in series with the field winding of the motor to adjust the field strength to give additional speed adjustment. This method of speed control has been applied successfully to motors up to 25 hp and larger.

2 INDUCTION STARTER FOR D-C MOTOR. For low inertia loads, an induction coil may provide sufficient current limiting for d-c motor starting. The circuit in Fig. 2 shows the use of a magnetic amplifier to time the operation of an induction starter.

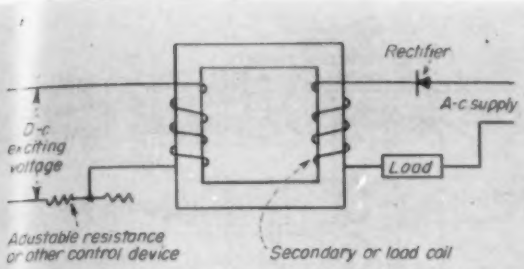
In accordance with electrical theory, a coil placed in a d-c circuit has the effect of resisting any increase or decrease in the magnitude of current. But when steady-state conditions of current are reached, the coil has little effect. Thus, when the main contacts of this circuit are closed, current builds up slowly in the shunt field. The control coil of the magnetic amplifier is in series with the field winding and carries the same current.

At start, then, the control coil current is low so the impedance of the amplifier load coils is high. The load coils limit the rate of rise of the motor armature current. As the current in the field winding increases progressively, the impedance of the amplifier load coils drops proportionately. Thus, less resistance is offered to the flow of armature current, which builds up steadily to rated value. When the back emf of the motor armature reaches its normal operating magnitude, the relay contacts close, short circuiting the magnetic amplifier. The relay can be omitted where the motor runs only for short periods, such as required to position a tool carriage or close a valve.

3 MOTOR LOAD CONTROL. This circuit makes it possible to maintain constant load on a motor. One application for this system is the control of a centrifugal water pump. The magnetic amplifier circuit provides for the maximum rate of flow without overloading the motor. The d-c motor has a portion of its field connected to an a-c source through the magnetic amplifier. The control coil of the amplifier is connected across the interpole windings of the motor. Therefore, the voltage applied to the control coil is proportional to the load current passing through the motor armature.

When the motor load tends to increase beyond the preset value, the amplifier control coil current also rises, building up the saturation of the iron core of the amplifier. This allows more current to flow through the rectifier to strengthen the motor field and reduce the motor speed. When the load on the motor load decreases sufficiently, its field strength is reduced and its speed increased to bring the load back to the normal rating. This corrective action occurs constantly, in much the same manner as a vibrating stack voltage regulator. Of course, the magnetic amplifier has no moving parts so that unstabilized performance has no effect on service life.

4 GENERATOR LOAD CONTROL. The current output of an electrical generator can be held constant at any predetermined level by this means. To raise generator out-



tion of the iron core. If the flux saturation is low, the load coil impedance is high. However, a current through the control coil sets up its own flux lines, partially or completely saturating the iron. The impedance of the secondary coil drops.

By adjusting the value of the current in the control coil, the secondary impedance—and, hence, load current can be controlled. The rectifier is included to prevent the flow of power from secondary to primary coil by transformer action.

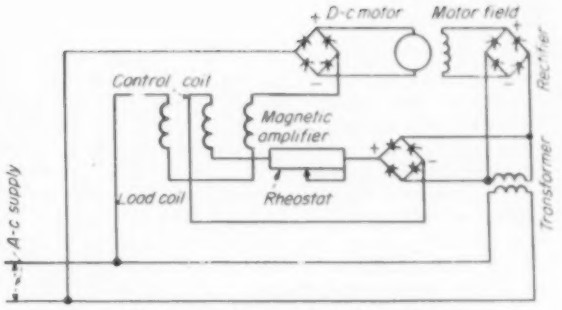


Fig. 1—Speed control of a d-c motor.

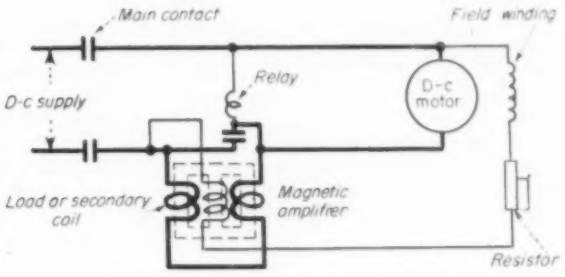


Fig. 2—Induction starter for a d-c motor.

put it is necessary to strengthen the field; whereas to step up motor output, field strength must be reduced.

When the amplifier control coil detects an overload, the impedance of the load coil decreases, increasing the strength of the auxiliary field. This has the effect of reducing the net or effective flux threading the armature coils. Terminal voltage drops somewhat, simultaneously relieving the overload.

Should the value of load current fall for any reason, the control coil excitation becomes less also. The impedance of the load coils rises, lowering the voltage across the auxiliary field. With the reduction in the strength of the field opposing it, the main field can deliver more effective flux. Thus, the terminal voltage is stepped up and the generator load restored to its rated value.

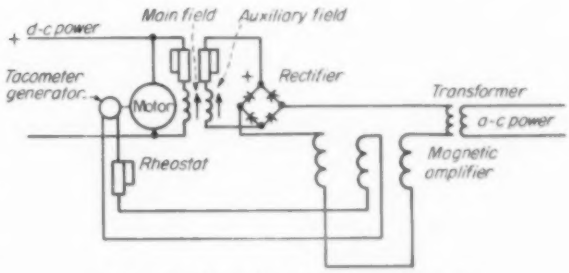


Fig. 3—Load limiting circuit for a d-c motor.

5 TACHOMETER SPEED REGULATION. The circuit in Fig. 5 is designed to maintain the speed of a motor constant. It is especially applicable to multi-motor drives where the speeds of the various sections must be closely synchronized. Paper or textile machines having continuous strips of material passing through several sets of rolls are examples of possible applications. Customarily, each set of rolls is driven by a separate motor.

The drive motor is coupled to a small tachometer generator which has a permanent magnet field. This field is constant in strength and requires no exciting current. The tachometer has a d-c armature that furnishes power to the control coil of a magnetic amplifier. This current can be adjusted by a rheostat to set the desired motor speed.

When the motor speed goes above the predetermined value, the tachometer voltage increases beyond its normal rating. The control current also rises, resulting in less impedance in the load coils. The excitation of the auxiliary field increases, causing a net increase in the effective motor field. The main and auxiliary fields are wound so that fluxes are additive. Because of the increase in field strength, the motor decelerates to the set value. Should speed go below this level, an opposite correction occurs.

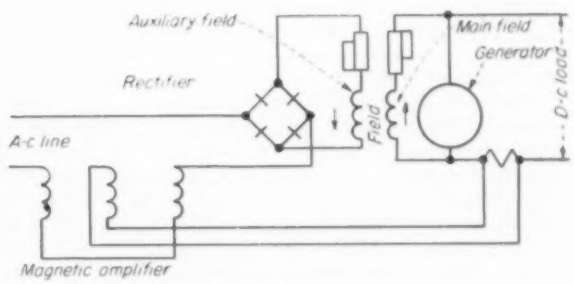


Fig. 4—Load limiting circuit for a generator.

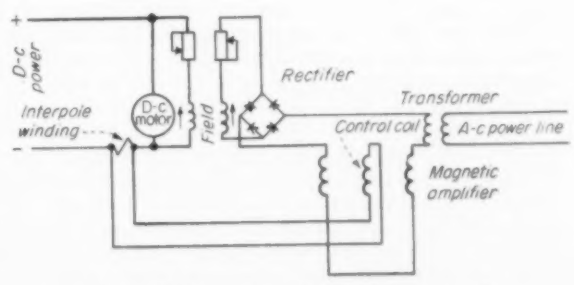


Fig. 5—Tachometer regulation of motor speed.

6 A-C MOTOR STARTER. Operation of this circuit is much the same as that explained above for the d-c starter. However, the closing coils are equipped with electrical interlock contacts to provide additional assurance for the correct sequence of resistor cutout. At the proper values of back voltage and current, cutout No. 1A closes. Interlock contact No. 1A closes simultaneously. Note that this contact is in the circuit of the No. 2A closing coil. Therefore, this coil cannot function until the first portion of the starting resistor has been by-passed. Likewise, after the cutout and interlock contacts No. 2A have closed, closing coil No. 3A can operate to short the entire resistor in the armature circuit.

The magnetic amplifier increases the effect of armature current changes so that the contactor operation is extremely accurate. This is an important feature when the starting resistor has a great number of taps, each of which is to be by-passed in sequence. The voltage and current differentials between the functioning of adjacent contacts are small so that precise measurement of values is necessary to guarantee proper operation. The electrical interlocks also serve to prevent malfunctioning. Without these design features, it is difficult to adjust the starter so that the contacts act in correct sequence. Furthermore, after extended use the initial settings become more difficult to hold.

7 SLIP REGULATOR. In some machine applications, the drive motor is subjected to high peak loads of short duration. Unless compensated for, this condition results in large variations in the demand on the power supply for the machine. If the drive motor is fed from a motor-generator set, the latter must be oversize to accommodate the peaks.

This varying demand can be equalized by putting a fly wheel on the shaft of the motor-generator set. When the load is heavy the speed of the set is reduced and the excess power is furnished by the fly wheel. When the load decreases the speed is increased to store energy in the fly wheel to meet the next load peak. Magnetic contactors, responsive to the load, change the secondary resistance of the wound rotor induction motor driving the fly wheel and the generator. The uniformity of power demand depends upon the accuracy of the control. This diagram shows how a magnetic amplifier can be used to magnify the variations in load to actuate the contactors controlling the secondary resistor.

Current input to the motor—which is directly proportional to load—is sensed by the amplifier through a transformer and plate rectifier. At peak currents, the impedance of the amplifier load coils drops, increasing the voltage across the slip relays. The latter are set to act at various voltage levels. Thus, depending on the magnitude of the overload, one or more of the slip relay contacts are pulled open. This, in turn, causes the corresponding accelerating relays to open, putting one or more sections of the secondary resistors in the rotor circuit. This causes the motor to slow down.

When the peak load is passed, the slip and accelerating relays close once again, by-passing all rotor resistance. The motor resumes normal speed.

8 DYNAMIC BRAKING CONTROL. A hoist motor may be designed to lift the load and also to supply much of the braking effort needed to retard the load when it is being lowered. During a lift, the motor consumes positive power. In braking, the motor actually performs as a generator, returning power to the electrical supply lines. This may be designated as negative power. The hoist may have

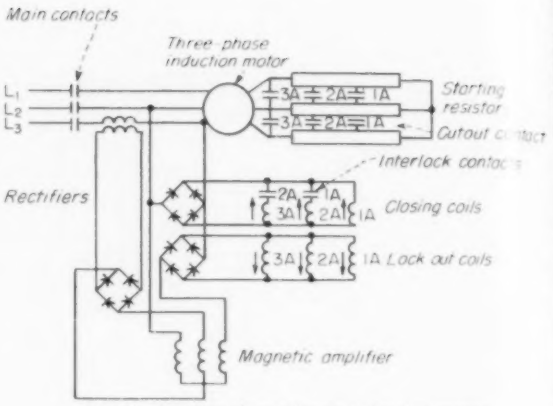


Fig. 6—Starting circuit for an induction motor.

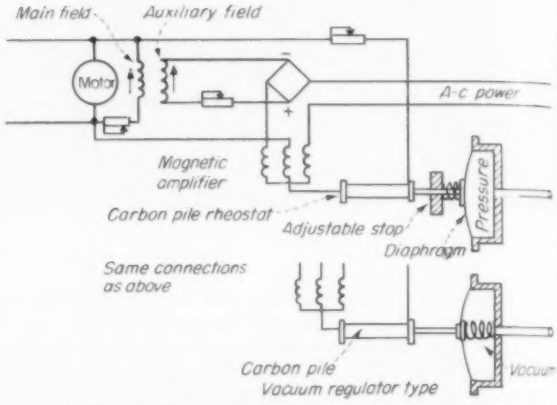


Fig. 9—Signal amplifier for sensing elements.

a counterbalance in excess of the weight of the car to offset some of the load during hoisting and lowering.

The variation between positive and negative motor load requires the use of two control windings, *A* and *B*. Coil *A* provides a reference flux and coil *B* is responsive to the amount and direction of the armature current. In the circuit of Fig. 8, a Ward-Leonard type of speed control is employed. The generator shown is part of a separate motor-generator set and supplies adjustable voltage to the hoist motor. The drive motor for the generator is not shown.

When the motor load is positive, coils *A* and *B* are additive and act to increase the generator voltage in proportion to the load. When the load is negative, coil *A* opposes coil *B* to reduce the generator voltage. The motor now becomes a generator driving the motor-generator to return power to the line and slow the speed of the hoist.

9 SIGNAL AMPLIFIER. The transducer is a component that appears more frequently in the control circuits of machines. Broadly defined, the transducer is any element that changes a physical quantity to an electrical signal. Transducers are available that are responsive to light, heat, weight, pressure, sound, size, speed, acceleration and other quantities. The signals from transducers can be fed to circuits controlling machine operations.

Usually, transducer signals are small in magnitude. Between the sensing element and the control element a stage must be added to step up the signals to usable levels. A magnetic amplifier is a suitable device for this purpose.

The diagram in Fig. 9 shows a diaphragm type of pressure or vacuum regulator. The diaphragm acts against a

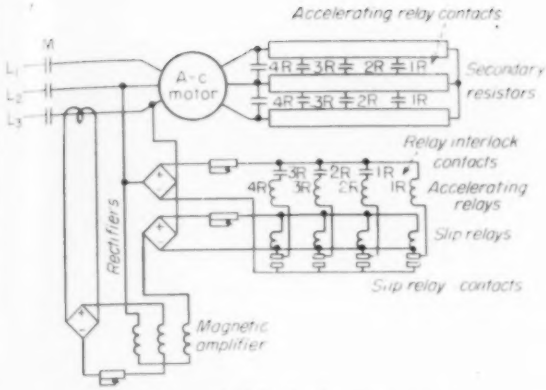


Fig. 7—Control of flywheel energy storage.

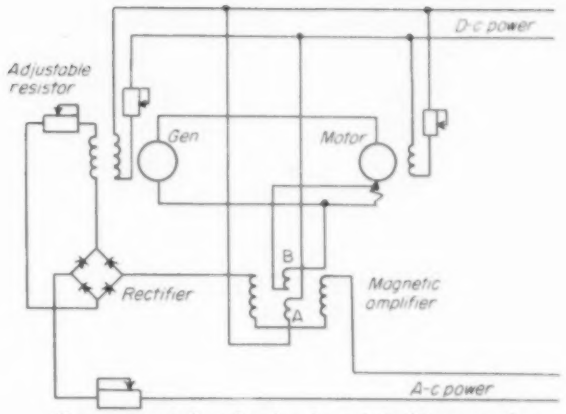


Fig. 8—Circuit for adjusting dynamic braking operation.

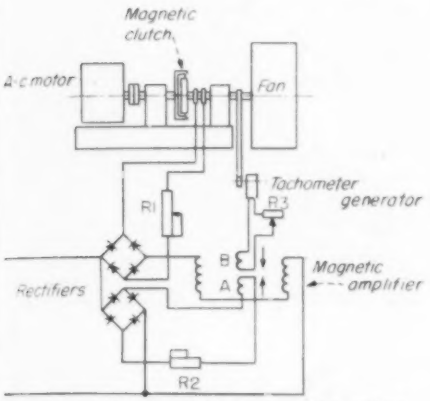


Fig. 10—Slip control for a magnetic coupling.

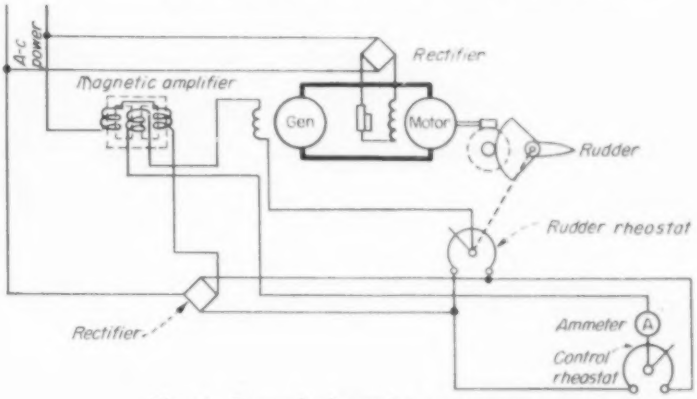


Fig. 11—System for increasing servo response.

carbon pile resistor. The latter is connected in series with the control coil of a magnetic amplifier. The load coils of the amplifier are in series with the auxiliary field of a motor. This motor may be operating a pump or an air compressor. Assume that it controls a pump that maintains a fixed water level. A small drop or rise in the water level brings about an adjustment in the motor field to change the pump speed. This restores the water to the desired level. Float switches are used for this purpose but are often difficult to inspect and maintain. Water pressure is easy to measure, using a pipe from the tank to the controller.

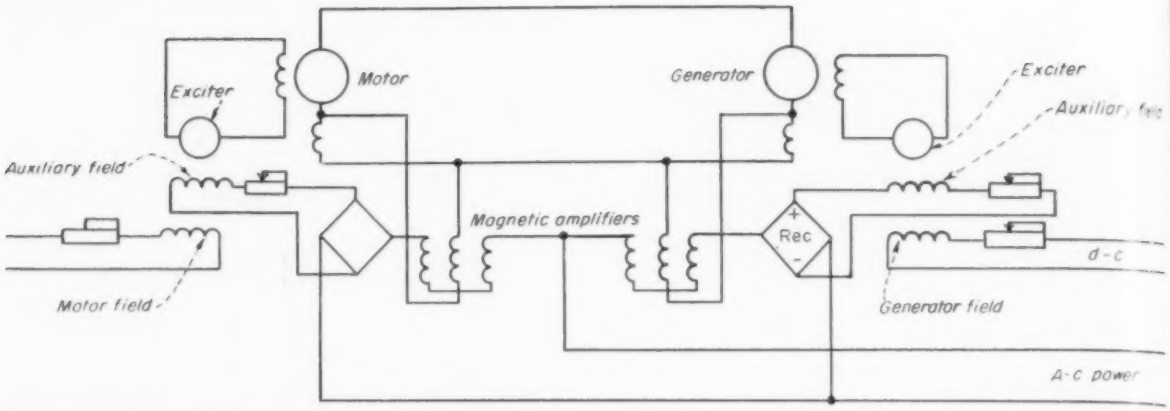
10 ADJUSTABLE SLIP CLUTCH. The construction of a magnetic clutch is similar to that of a squirrel cage motor. The rotor of the clutch may be connected to the load, while what substantially resembles the stator of the squirrel cage motor may be coupled to the shaft of the drive machine. The "stator" or field windings of the clutch are d-c excited. When the drive motor is energized, the field flux rotates in relation to the clutch rotor. The torque transmitted through the clutch is directly proportional to the magnitude of d-c excitation.

Using the magnetic amplifier circuit shown in Fig. 10, the slip of the clutch can be regulated. By this means, the speed of the load—a fan in this case—can be adjusted to any desired value. The rheostat R_1 is the speed setting device. Once adjusted, the speed is held constant by action of this circuit.

The clutch coils receive power from a rectifier bridge. A tachometer generator, which is belt-connected to the driven member of the clutch, maintains the fan speed constant by adjusting the current in the magnetic amplifier control coil *B*. The flux set up by the latter opposes the reference coil *A*. An increase of the fan speed reduces the control magnetism in the amplifier and increases the clutch slip. A decrease in fan speed increases the control flux in the amplifier to reduce the clutch slip. Fans or centrifugal pumps, whose output varies as the cube of the speed, are well adapted for this type of control.

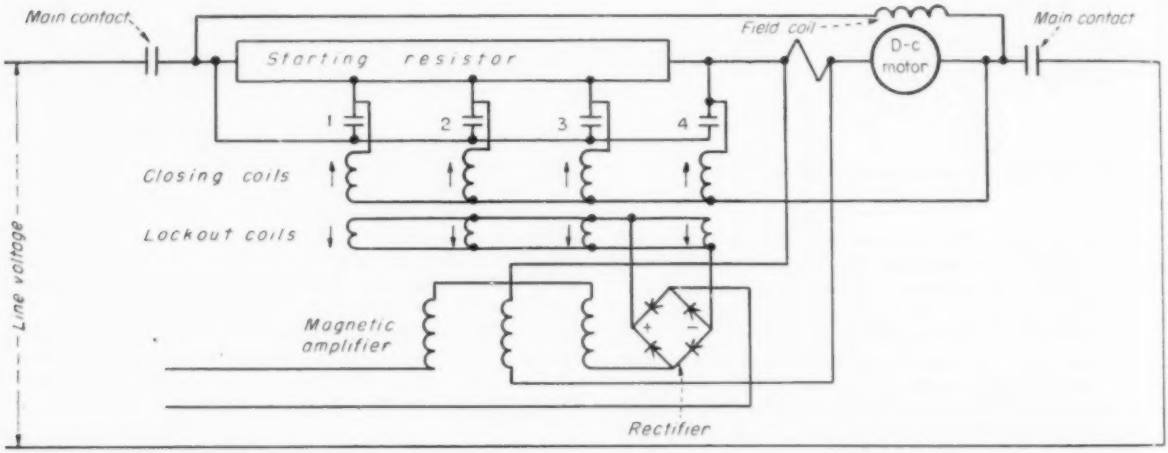
11 SERVO CIRCUIT. Response is a critical characteristic in servomechanisms. It is desirable, of course, to have the output movement follow the error signal as closely as possible. Now, rate of response is normally proportional to the magnitude of the error. To speed up response, the designer may include an "error intensifying" device in the circuit which amplifies the input signal. Under ideal conditions, the amplification should drop off abruptly at the null point of the servo system to prevent the output service from overshooting the desired position. The magnetic amplifier provides this type of performance.

An example of such an application is the rudder positioning servo system sketched in Fig. 11. When the steering rheostat is moved, it applies voltage to the generator field to furnish power to the rudder motor. As the rudder is turned it moves the rudder rheostat arm in a direction to reduce the current in the amplifier control coil. The rheostat supply current from this amplifier drops proportionately. The amplifier reduces this current slowly until the neutral point is reached. Here, the current decreases abruptly to stop the rudder motor. This method can be used for the remote control of dampers, valves and for similar applications.



12 DOUBLE LOAD CONTROL. This is a combination of the circuits shown in Figs. 3 and 4. The use of two magnetic amplifiers makes it possible to maintain the motor load at an extremely precise, predetermined amount. The motor and generator illustrated above are connected electrically, not mechanically. The generator is powered by a separate motor, not pictured. The motor drives machine elements, such as the rolls of a blooming mill.

Both motor and generator have an individual magnetic amplifier to control field strength. Each amplifier is responsible to the same load current, which passes through both armatures. At start, the motor has maximum field strength. The generator field starts at zero strength and is gradually built up to the desired operating speed and until the generator delivers its maximum voltage. When a further increase in motor speed is required, the motor field is reduced to provide the increase. There are several interlocking control connections that are necessary, but these are omitted to simplify the diagram.



13 D-C MOTOR STARTER. This is a standard d-c motor starter of the counter emf type. Initially, the full starting resistor is in series with the armature to limit the current inrush to a safe value. The resistor is tapped in four places by individual magnetic contactors, each designed to close at a different value of counter emf or back voltage. The starter automatically cuts out the resistor in four steps until the resistor is completely out of the circuit at rated motor speed.

As the motor armature accelerates, the back voltage builds up. At a given value of back voltage, the magnetic field of coil No. 1 attempts to close its contacts. However, this closing is prevented by the field of the corresponding lockout coil, which acts in the opposite direction to that of the closing coil. Contacts No. 1, therefore, cannot close until the armature current has decreased to the predetermined value.

When the desired conditions of both voltage and current are reached, contacts No. 1 close, shorting-out or by-passing the first section of the starting resistor. This increases armature current, allowing the motor to accelerate further. Then, when the second set of counter emf and current conditions is satisfied, contacts No. 2 close. This process continues until contacts No. 4 are closed and the motor is at rated speed.

The lockout coils receive power from a rectifier through the magnetic amplifier. The d-c control coil of this amplifier is connected across the interpole windings of the motor and measure armature current. A one percent change in armature current can cause 100 percent change in the flux of the lockout coil. This yields an accurate control of the accelerating current. Any change of friction in the contactor movement is of small importance compared to the wide change in the strength of the lockout coil. With this circuit, acceleration of the motor can be precisely controlled since the circuit is sensitive not only to back voltage, but to armature current as well.

The application possibilities for this circuit are varied. The magnetic amplifier acceleration control might be included in the operating circuits of a traction motor. Then, regardless of how abruptly the operator may actuate the accelerator pedal or switch, the vehicle will increase its speed at a rate that cannot upset passengers or cargo. Another application might be in machine tool drives.

Teflon stop-cock in this burette prevents sticking.

Teflon

Components and Coatings

Table I—Properties of "Teflon"

Property		Method	
Tensile strength,	77 F, psi	D638-46T	1500–2500
Elongation,	77 F, psi	D638-46T	100–200
Flexural strength,	77 F, psi	D790-45T	did not break
Stiffness,	77 F, psi	D790-45T	60,000
Impact strength			
Izod	– 70 F, psi	D256-47T	2.0
	77 F, psi	D256-47T	4.0
	170 F, psi	D256-47T	6.0
Hardness, Durometer		D676-47T	D55–D70
Compressive stress at 0.1% deformation, psi		D695-44T	1,700
Coefficient of linear thermal expansion per deg, 77–140 F		D696-44	5.5×10^{-5}
Thermal conductivity, 0.18 in B.T.U./hr./sq. ft./F./in		(1)	1.7
Specific heat, B.T.U./lb/F		.....	0.25
Deformation under load 122F., 1,200 psi, 85 hrs., percent		D621-48T	4–8
Heat-distortion temperature, 66 psi, F.		D648B-45T	270
Dielectric strength, short-time, 0.080 in., V/mil		D149-44	400–500(2)
Surface arc-resistance, sec		D495-42	700 (3)
Volume resistivity, ohm-cm		D257-46	10^{18}
Surface resistivity, 100% R.H., megohms		D257-46	3.6×10^{6}
Dielectric constant,	60 cycles	D150-47T	2.0
	10^3 cycles	D150-47T	2.0
	10^4 cycles	D150-47T	2.0
	10^5 cycles	D150-47T	2.0
Power factor,	60 cycles	D150-47T	0.0005
	10^3 cycles	D150-47T	0.0005
	10^4 cycles	D150-47T	0.0005
	10^5 cycles	D150-47T	0.0005
Water-absorption, percent		D570-42	0.0
Flammability, in./min		D635-44	nonflammable
Specific gravity		D792-48T	2.1–2.3
Resistance to weathering		.....	excellent (4)

Tests have been performed by A.S.T.M. methods unless otherwise indicated. Data shown are average values and should not be used for specifications.

(1) Thermal conductivity measured by Cenco-Fitch apparatus.
(2) Value is 1,000–2,000 volts/mil in thicknesses of 5 to 12 mils.
(3) Does not track.
(4) No detectable change after 5 years of outdoor exposure in Florida.

POLYTETRAFLUOROETHYLENE, or "Teflon", is a plastic that frequently can be used under severe operating conditions. Its outstanding properties, Table I, on which are based its many applications are its toughness over a wide range of temperatures, its excellent electrical characteristics over a wide range of frequencies, its chemical inertness, heat resistance, low coefficient of friction and non-adhesiveness. Its major fields of application are as gaskets, packing and liners in hydraulic and chemical equipment, as an electrical insulator and as a chemical resistant and non-adhesive finish.

Teflon is capable of continuous service at temperatures from —90 to 500 F. Its impact strength is high in this temperature range. At 620F the mechanical properties change sharply and at 750 F decomposition to a gaseous phase occurs. At temperatures below transition (620F) it is remarkably stable. Molded bars show a loss in tensile strength of only one percent after one month at 480 F. At 570 F this loss becomes 10 to 20 percent.

Fillers can be incorporated into Teflon to increase stiffness, hardness and compressive strength and to reduce deformation under load. Materials generally used include carbon, graphite, asbestos, talc, copper powder and zircon and glass fibers.

The outstanding electrical properties of Teflon are its low power factor even at high frequencies, its high dielectric strength and its good arc resistance. Because the surface of the material vaporizes it can be exposed indefinitely with no production of a carbonized path. Its extremely low water absorption assures retention of its electrical

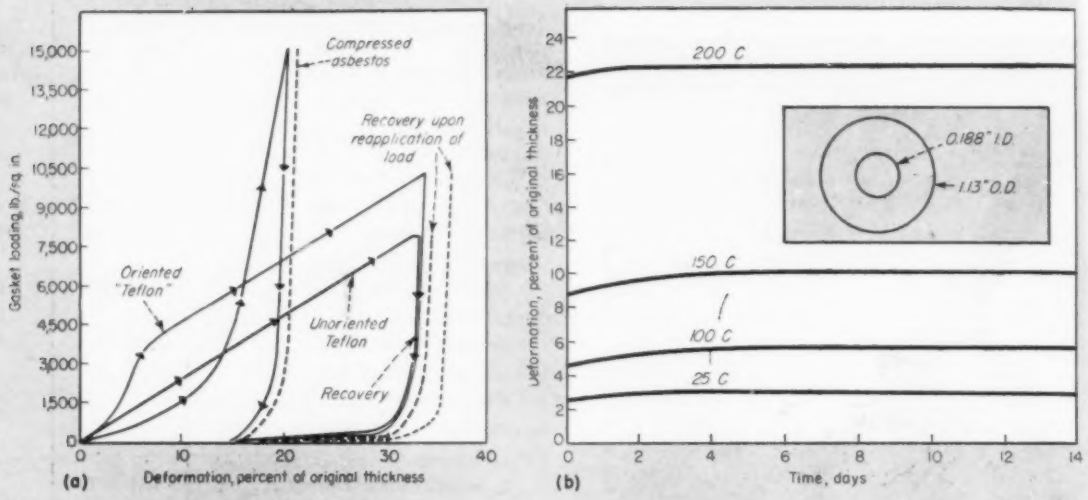


Fig. 1 – (a) Compression and recovery curves, (b) Effects of long-time compression on solid Teflon gaskets.

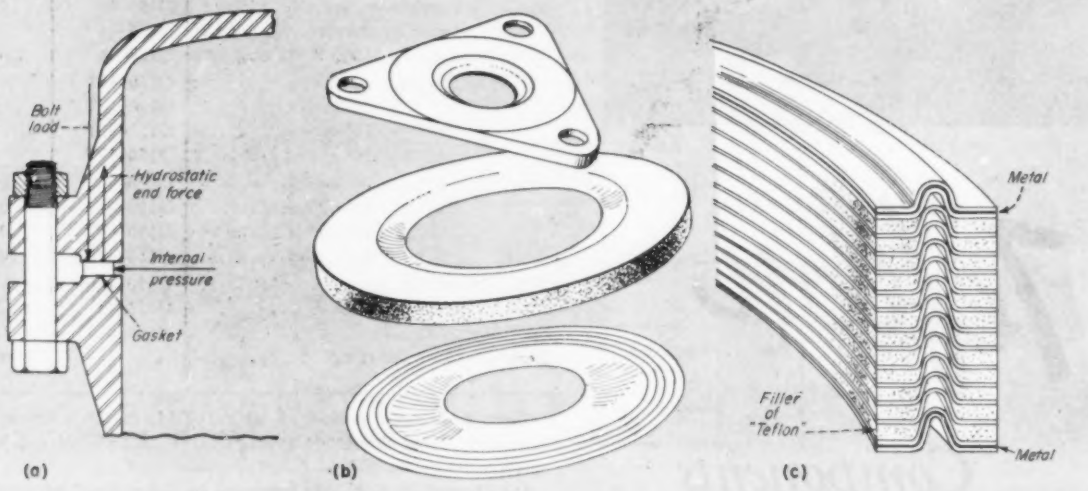


Fig. 2 – (a) Three major forces acting upon a gasket. (b) Teflon envelope gaskets. (c) Spiral wound Teflon metal gasket.

properties even after prolonged exposure to moisture.

Teflon is available as molded parts, extruded and molded shapes and as aqueous dispersions for finishes.

Gaskets and Packing

Teflon is an effective gasket material because of its chemical inertness and good mechanical properties over a wide range of temperature. It is attacked by only molten alkali metals and fluorine at elevated temperatures and pressures.

Its mechanical properties Fig. 1(a) are comparable to those of high grade rubber bonded asbestos, except for the compression characteristics. It compresses at a uniform rate with increasing load whereas with asbestos the converse is true. Recovery upon removal of the load proceeds at about the same rate for both materials. A lack of resiliency is indicated by the steepness of the recovery curves. In applications involving variations in temperature the pressure on the gasket changes through expansion and contraction of the flanges and bolts. This may necessitate spring loaded bolts.

Under long time compressive load, Fig. 2(b), the tendency for Teflon to cold flow is not excessive and equilibrium is reached after only the first few hours of load application at a given temperature and pressure. No further deformation will occur until the load or temperature is changed.

Gaskets fabricated from Teflon, Fig. 2, include solid, jacketed, spiral wound, and impregnated types.

Solid gaskets. Solid Teflon gaskets are used in applications where standard design flanges are used. For low pressure applications, i.e., 150 to 300 psi raised flanges are normally used. Higher pressures require a confining arrangement such as tongue and groove or male and female flanges. Pressures as high as 30,000 psi have been withstood by tongue and groove flanges.

Table II — Physical Properties of Filled "Teflon" Compositions

Filler Proportions in Percent by Weight

Property	Units	A.S.T.M. Test	Unfilled "Teflon"	33% Carbon	50% Carbon	67% Carbon	25% Graphite	50% Graphite	75% Graphite	52% Asbestos	33% Talc	80% Copper	80% Zircon
Tensile Strength	psi	D638	1,800	2,375	2,300	1,790	2,200	2,425	1,990	1,780	1,700	2,300	
Elongation	percent	D638	100-200			5.9			1.2	0.2	4.7		
Modulus of Elasticity	psi	D638	58,000	421,000	431,000	574,000	309,000	378,000		1,190,000	510,000		
Flexural Strength	psi	D790	Did not break	6,100	6,200	3,980	5,700	4,560	3,200	4,080	Did not break	4,170	4,200
Compressive Strength	psi	D695	Did not break			8,650		5,400	5,600			2,900	
Impact Strength, Izod	ft-lb. in.	D256	4.0	1.78	1.45	0.8	2.14	0.86		0.86			
Deformation underload 2000 psi., 24 hr.	percent	D621	25	1.7		0.9				0.3			
Hardness, Shore "D"		D676	55			75		68	70	75	65	82	90
Density of Molding	gm/cc		2.14	2.13	2.08	1.95	2.13	2.10	2.16	2.4	2.4	5.0	3.4
Thermal Conductivity	B.T.U./ hr/sq ft./F/in	(Cenco-Fitch)	1.7			6.8		9.5	19.5	4.2		7.5	
Electrical Resistivity	ohm-cm		10^{15}			0.0		87.6	0.0	2.6×10^{12}		2×10^{5}	
Water Absorption	percent	(2-hour boil)	0.0		0.01	0.07	0.0	0.0	0.0	0.05	0.03		

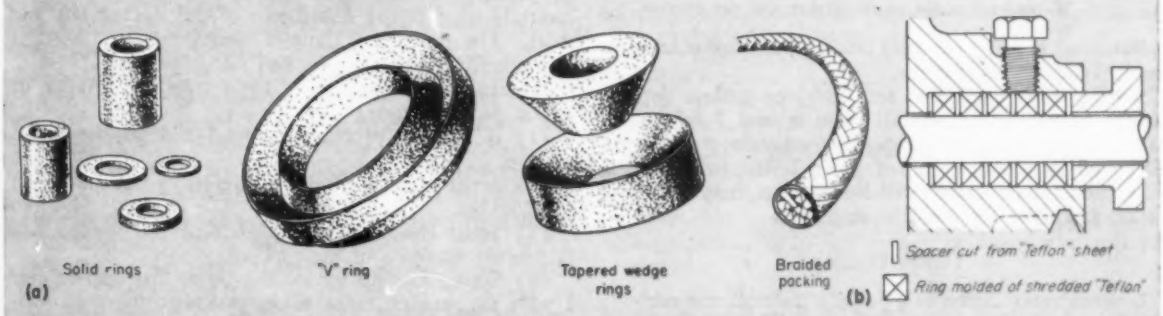


Fig. 3 — (a) Teflon packings include solid rings, V-rings, and tapered wedge rings. (b) Stuffing box packed with Teflon.

Envelope Gaskets. These consist of a soft filler material covered by a Teflon jacket. They were developed for applications where flange misalignment and low bolting pressures would prevent seating of solid gaskets. Glass, porcelain and glass-lined equipment fall into this category.

Fabric reinforced rubber, soft asbestos sheet and metal fillers can be used to provide the properties desired in the envelope gasket.

Spiral wound metal gaskets with a Teflon filler are suitable for high pressure chemical applications. Stainless steel, Monel and other corrosion resistant metals are used for these applications.

The development of dispersions has introduced new gasket materials. Coatings can be applied to gasketing materials with desirable compression characteristics to provide better performance or to lower cost.

Metal wire inserts have been used in V-shaped gaskets to prevent flow of the Teflon out of the seat.

Bolt Loading Calculations

Bolt loading calculations for Teflon gaskets are based on the procedure suggested in the 1949 ASME Boiler Construction Code, Section VIII, Appendix III, the formulae used are:

$$W_{m1} = H = Hp + 0.785\, G^2 P + (2b \times 3.14\, GmP)$$

and

$$W_{m2} = H_y = 3.14\, bGy$$

where:

W_{m1} = required operating bolt load
H = hydrostatic end force
H_p = compression load on gasket
W_{m2} = required initial bolt load for normal conditions—no internal pressure
H_y = load on gasket to assure a tight joint
b = effective gasket joint-contact-surface seating width
G = diameter at location of gasket load reaction
P = internal working pressure
y = yield stress, or the minimum stress required to effect

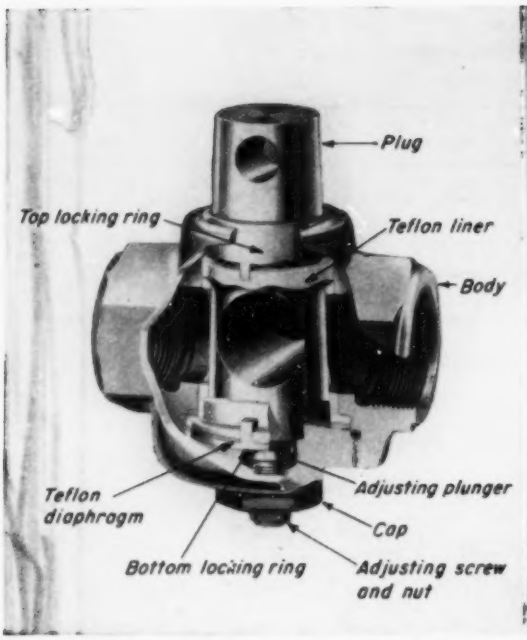


Fig. 4—This plug type valve manufactured by the Duriron Co. uses a Teflon liner and diaphragm. The liner affords an excellent seat for the plug, is chemically resistant and self lubricating.

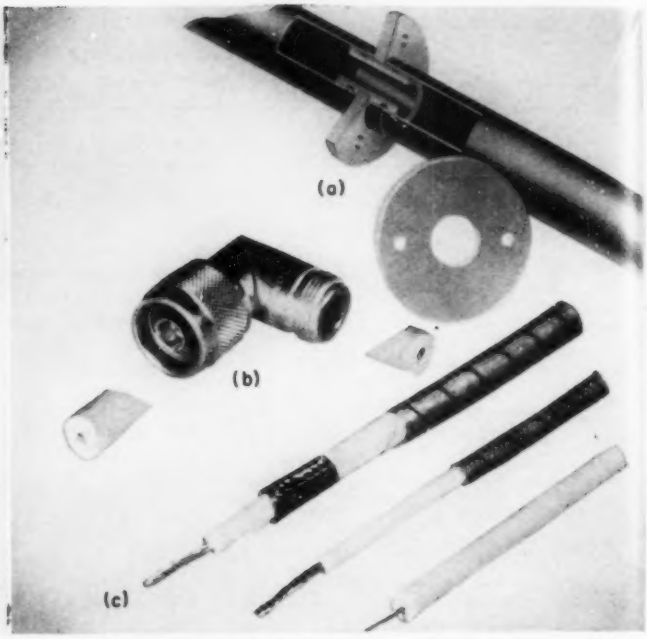


Fig. 5—Teflon coaxial spacers (a) and inserts for connectors (b) give improved efficiency to television and FM transmission. High voltage, high frequency wires (c) have Teflon insulation.

a seal against even slight fluid pressure.

m = the gasket factor, or the minimum required ratio of resultant stress on the gasket and the internal pressure.

Values of m and y for solid teflon gaskets are obtainable from gasket manufacturers.

Bolting loads needed to seat envelope gaskets depend largely on the filler material. The m and y values for envelope gaskets with compressed asbestos and harder fillers will approach those of solid Teflon, whereas for softer fillers these values will lie between those for solid Teflon and those for the filler material.

Teflon Packing

In considering Teflon as a packing material, the rubbing speed is of prime importance. Frictional heat is developed at a slower rate in unlubricated Teflon packing than in other materials because of its low coefficient of friction. However, its low thermal conductivity retards heat dissipation and its high coefficient of thermal expansion reduces clearances as the temperature rises.

Applications for Teflon packings fall into two general classes, based upon shaft surface speed:

(1) Low speed applications such as for valve stems, reciprocating pumps and agitators, where rubbing speed is less than about 150 feet per minute and the seal is effected by direct contact between the packing and shaft.

(2) High speed applications, such as centrifugal pumps where rubbing speeds exceed 150 ft per min and where an annular space is maintained along the shaft to prevent contact between shaft and packing.

Low speed Teflon packings, Fig. 3(a), include solid rings, tapered wedge rings, braided packing, V-rings and impregnated packings.

A typical high speed pump packing is shown in Fig. 3(b). Rings made from shredded Teflon held together with a strong binder have good form stability to insure maintenance of clearance along the shaft and have some resilience and abrasion resistance. The molded rings are usually installed with thin spacers of solid Teflon, carefully sized to the dimensions of the stuffing box and shaft. The packing is "run-in" carefully until a small uniform annular space is formed along the shaft.

Mechanical features needed for successful operation of Teflon packings are:

(1) A smooth, preferably ground and polished shaft surface.

(2) Small gyration of shaft—preferably not more than 0.002 inches.

(3) Small clearances at the ends of the stuffing box to prevent extrusion of the packing.

(4) Spring loading for stuffing boxes that operate over a wide temperature range to accommodate the high thermal expansion of the Teflon without exerting excessive pressure against the shaft.

Other Teflon hydraulic components include valve seats, valve diaphragms, valve liners and O-Rings.

An interesting Teflon valve application is contained in a corrosion resistant plug valve, Fig. 4, manufactured by the Duriron Company. A Teflon liner between the plug and the valve body serves as both valve seat and lubricant. The advantages derived from this type construction include:

(1) Better seal through ability of the liner to sustain higher plug pressures that would normally destroy film contact of lubricants and would cause seizure in metal to metal contact.

(2) No lapping of valve and seat surfaces is required to produce a seal. This allows for lower cost and better interchangeability of parts.

(3) Better resistance to temperature and corrosion.

(4) No stuffing box and packing required.

(5) Reduced maintenance and simplicity of operation.

Teflon pump pistons and impellers have good serviceability where exceptional corrosion resistance is required. Its low frictional characteristics, toughness and wear resistance are other advantageous properties. Filled compounds

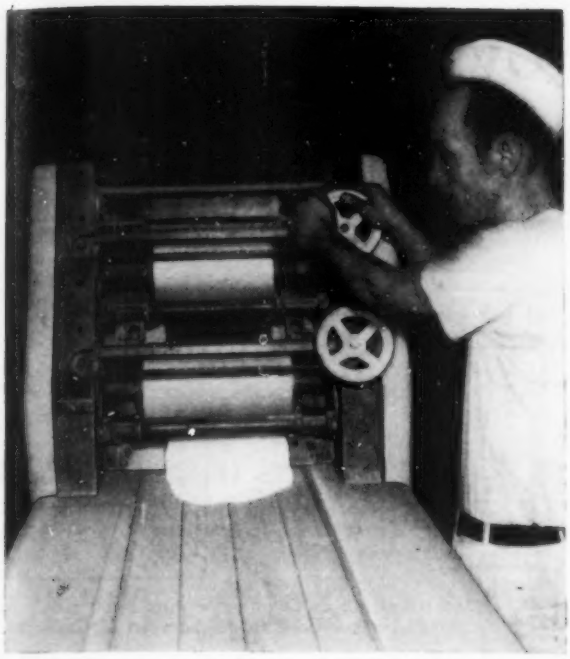


Fig. 6—**The rolls on this bread molding machine are covered with Teflon to prevent sticking of the dough. Many such applications take advantage of Teflon's non-adhesiveness.**

can be used where better rigidity is desired.

Expansion joints machined from Teflon tubing have been used with glass piping to take up slack caused by temperature changes and to provide maneuverability.

Glass fiber filled Teflon is expected to gain application as pipe and fittings to replace porcelain, glass and carbate piping. The chopped fiber affords better rigidity and resistance to cold flow and deformation. Extruded 1½" O.D. pipe is now under test at the Du Pont laboratories.

Teflon is used as an electrical insulator as molded parts or as wire covering. The covering can be either an extruded jacket, tape wrapping or dispersion coating.

Molded or machined parts Fig. 5 are used for coaxial spacers in television and FM transmission lines and as inserts for coaxial connectors. Low power loss and low dielectric constant are required for these applications.

In high voltage cables, Teflon insulation can be made to withstand almost any required voltage by increasing the thickness of the insulation.

Teflon tape is effective as a wrapping for insulation in motors, generators and conductors because of its good mechanical strength and ability to stretch.

Hermetic sealing between Teflon and metal is accomplished by a special technique. Copper powder is molded into the surface of a Teflon part at the section to be sealed. The irregularly shaped metal powder particles are securely locked into the surface. The copper surface is then electroplated to form a satisfactory metal surface that can be readily soldered.

Teflon Finishes

The development of Teflon aqueous dispersions has introduced a new field for this material—finishes that are chemically inert, resistant to high and low temperatures and that have outstanding anti-sticking properties.

These finishes have been used effectively in the baking industry on rollers that handle sticky dough; in the packaging industry to coat parts on heat sealing units to prevent cellophane, foil, polythene and other packaging materials from sticking to the unit. In packaging machines where glue is used parts coming in contact with the glue have been coated with Teflon to reduce cleaning time.

Other current or potential uses for these finishes include coating of glass stop cocks in laboratory equipment and coating of conveyor belts and chutes handling sticky material or parts.

For coating metals careful cleaning and preparation is required to obtain a satisfactory coating. Steel, iron, brass and chromium can be satisfactorily coated. It is not recommended for use on tin, copper, galvanized metal, cadmium plate or soft soldered joints.

Economic Factors

Both the material cost and fabrication cost of Teflon are high. However, this high initial cost is readily offset by increased service life, lower maintenance cost and improved performance.

Some case histories shown in Table III indicate the savings obtainable by replacement of lower cost materials with Teflon.

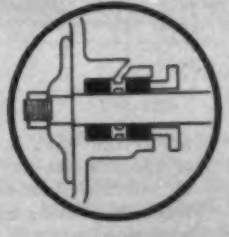
APPLICATIONS, information and technical data in this article were contributed by the E. I. duPont de Nemours & Company, Wilmington, Del.

Table III—Teflon Packing Case Histories

CASE 1 Conditions:
Chlorinated benzol 1 1/16" shaft, 1700 rpm

	Packing**	"Teflon"
Cost per unit	$3.20	$31.20
Service life	½ week	30 mo.
Cost per mo.—packing	25.60	1.04
—labor*	24.00	.10
TOTAL	$49.60	$1.14
Cost for 30 mo.	$1,488.00	$34.20
SAVINGS		$1,450

* estimated on basis of 2 man-hours per installation at $1.50 per hour
** conventional packing



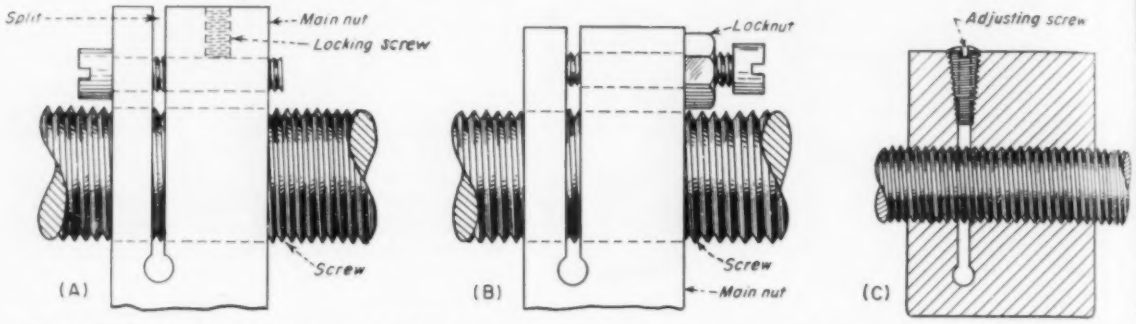
CASE 2 Conditions:
98% sulfuric acid, ⅞" shaft, 1750 rpm

	Packing*	"Teflon"
Cost per unit	$1.10	$11.28
Service life	½ week	27 mo.
Cost per mo.—packing	8.80	.42
—labor	24.00	.11
TOTAL	$32.80	$.53
Cost for 27 mo.	$886.00	$14.30
SAVINGS		$870.00

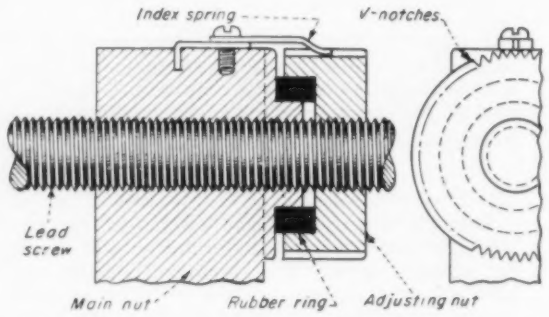
* conventional packing

How to Provide for Backlash

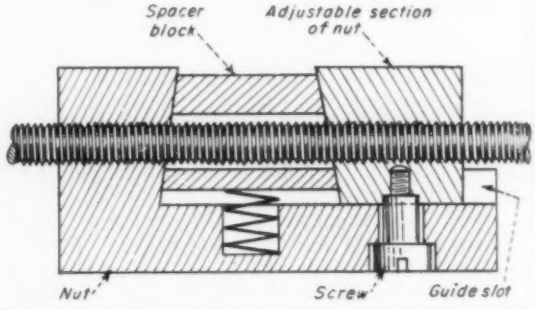
These illustrations are based on two general methods of providing for lost motion or backlash. One allows for relative movement of the nut and screw in the plane



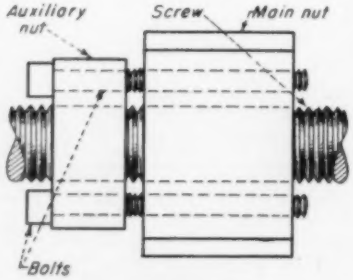
THREE METHODS of using slotted nuts. In *(A)*, nut sections are brought closer together to force left-hand nut flanks to bear on right-hand flanks of screw thread and vice versa. In *(B)*, and *(C)* nut sections are forced apart for same purpose



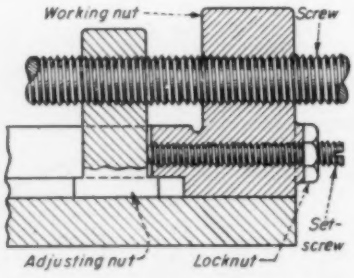
AROUND THE PERIPHERY of the backlash-adjusting nut are "v" notches of small pitch which engage the index spring. To eliminate play in the lead screw, adjusting nut is turned clockwise. Spring and adjusting nut can be calibrated for precise use.



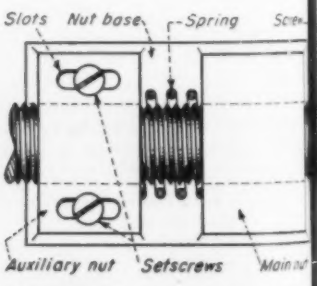
SELF-COMPENSATING MEANS of removing backlash. Slot is milled in nut for an adjustable section which is locked by a screw. Spring presses the tapered spacer block upwards, forcing the nut elements apart, thereby taking up backlash.



MAIN NUT is integral with base attached to part moved by screw. Auxiliary nut is positioned one or two pitches from main nut. The two are brought closer together by bolts which pass freely through the auxiliary nut.



ANOTHER WAY to use an auxiliary or adjusting nut for axial adjustment of backlash. Relative movement between the working and adjusting nuts is obtained manually by the set screw which can be locked in place as shown.

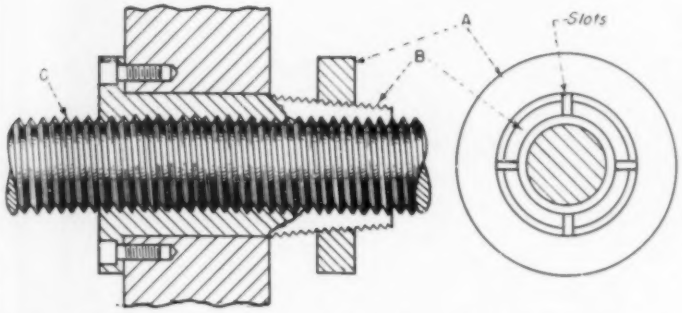


COMPRESSION SPRING placed between main and auxiliary nuts exerts force tending to separate them and thus take up slack. Set screws engage nut base and prevent rotation of auxiliary nut after adjustment is made

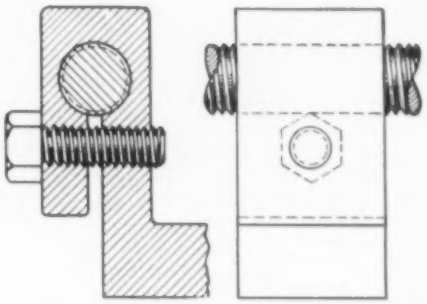
in Threaded Parts

CLIFFORD T. BOWER
London, England

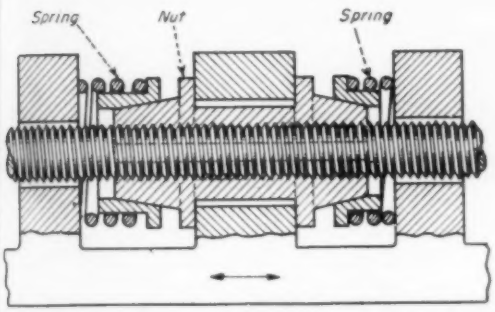
parallel to the thread axis; the other method involves a radial adjustment to compensate for clearance between sloping faces of the threads on each element.



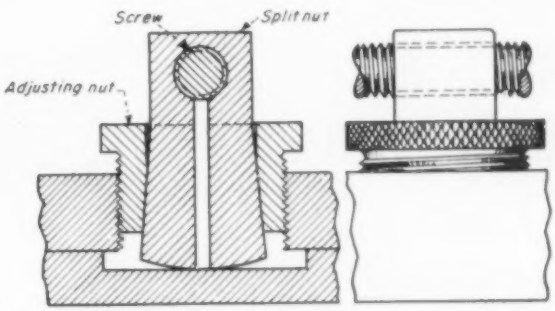
NUT *A* IS SCREWED along the tapered round nut, *B*, to eliminate backlash or wear between *B* and *C*, the main screw, by means of the four slots shown.



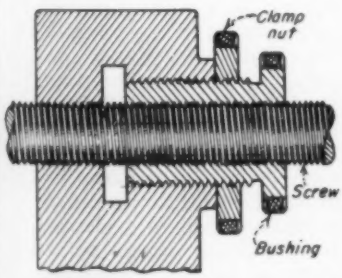
ANOTHER METHOD of clamping a nut around a screw to reduce radial clearance.



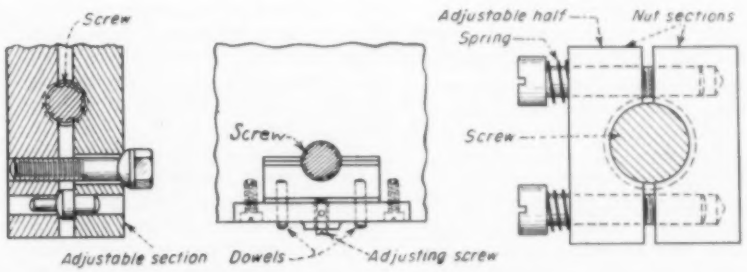
AUTOMATIC ADJUSTMENT for backlash. Nut is flanged on each end, has a square outer section between flanges and slots cut in the tapered sections. Spring forces have components which push slotted sections radially inward.



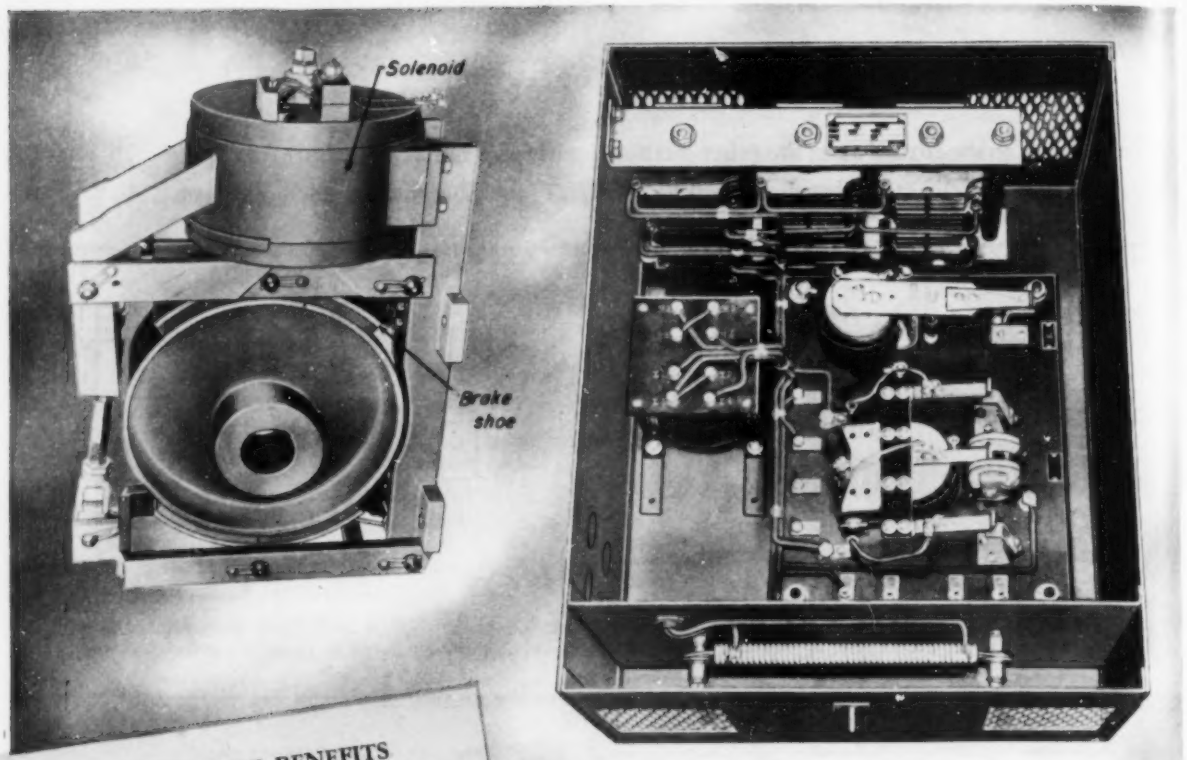
SPLIT NUT is tapered and has a rounded bottom to maintain as near as possible a fixed distance between its seat and the center line of the screw. When the adjusting nut is tightened, the split nut springs inward slightly.



CLAMP NUT holds adjusting bushing rigidly. Bushing must have different pitch on outside thread than on inside thread. If outer thread is the coarser one, a relatively small amount of rotation will take up backlash.



TYPICAL CONSTRUCTIONS based on the half nut principle. In each case, the nut bearing width is equal to the width of the adjustable or inserted slide piece. In the sketch at the extreme left, the cap screw with the spherical seat provides for adjustments. In the center sketch, the adjusting screw bears on the movable nut section. Two dowels insure proper alignment. The third illustration is similar to the first except that two adjusting screws are used instead of only one.



RECTIFIER BRAKE BENEFITS	Yes	No
Quiet Operation	✓	
Low Maintenance	✓	
High Efficiency	✓	
Trouble-free Service	✓	
Low Cost		✓

Fig. 1 — Components of a typical rectifier brake. At left, above, is shown the d-c electromagnetic brake, which is of conventional design. The rectifier and control devices are installed in the cabinet pictured at the right, above.

D-C Brakes

ROBERT C. MAY*
The Clark Controller Company

THE D-C OPERATED electromagnetic brake offers five major advantages not possessed by the a-c type of unit. In some applications requiring braking of an a-c motor, these advantages justify the added cost. For this reason, the rectifier brake is finding acceptance.

The rectifier brake consists of a d-c electromagnetic brake and a plate rectifier. The rectifier is connected to the a-c supply lines for the motor and provides sufficient d-c power for operation of the brake.

Usually, a control circuit is included in the rectifier assembly to improve the magnet performance. It is the purpose of the circuit to duplicate one inherent characteristic of an a-c brake not possessed by a simple d-c unit. The a-c magnet draws a high initial current for fast, powerful brake operation. But once the brake is fully opened, current drops off to a lower value for holding.

The control circuit of a rectifier brake normally includes a means for applying two separate voltages to the magnet coil and a timing device to select between these voltages. This provides high starting and lower holding currents.

Advantages of D-C Operation

The construction of an electrically operated brake is in many ways similar to that of a relay. The actuating force is supplied by a coil wound around an iron core. The core is not a single piece, continuous structure. For example, in a rectangular core which is a common design, one side is hinged. The hinged part, or armature, moves in reaction to the rise or collapse of the magnetic field threading the coil. This movement is transmitted to a set of contacts—in the case of a relay—or to a brake shoe. It is essential to know this simple description of brake design to understand the relative characteristics of a-c and d-c brakes.

Noise—in the form of hum and chatter—is frequently associated with a-c solenoids. This noise is not inherent, but is avoided only by careful design and quality control. A-c cores must be laminated to reduce eddy currents and the thin laminates tend to

* Mr. May is now with The Automatic Switch Company.

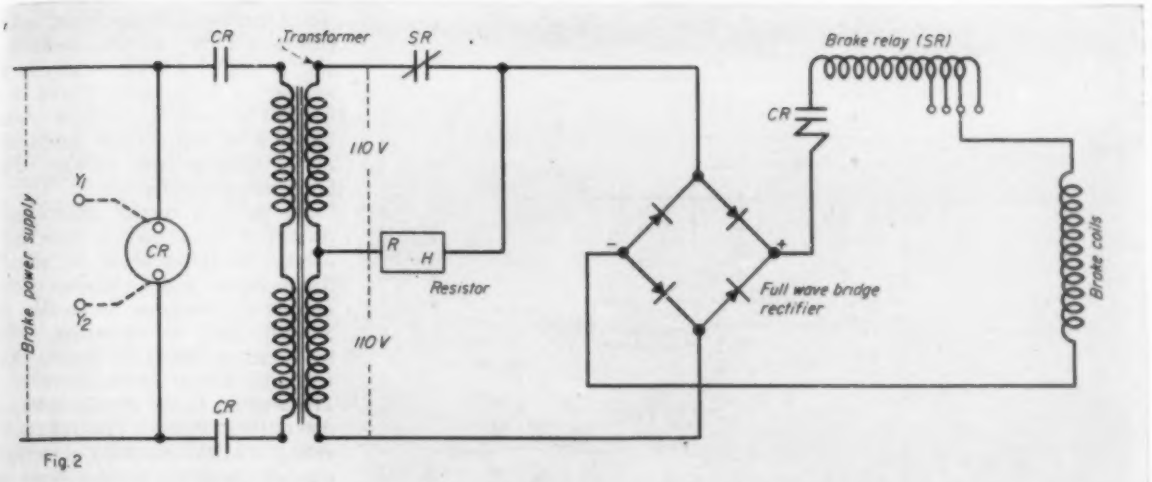


Fig. 2

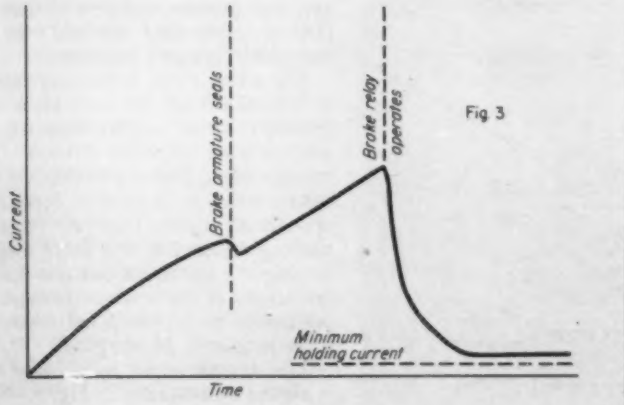


Fig. 3

Fig. 2—Schematic diagram for timing operation of a rectifier brake. This timing control is furnished by the manufacturer as part of the rectifier assembly, such as that shown in Fig. 1. The timing circuit is required to reduce the current flowing in the magnet coil after relay armature has released the brake.

Fig. 3—Plot showing the current fluctuations in the magnet coil of a rectifier brake. When the brake relay operates, a lower voltage is automatically impressed on the coil terminals.

for A-C Motors

vibrate with the frequency of the excitating voltage. Hum may be traced, also, to "hysterisis noise" which is set up by the molecular structure of the iron. Chatter is caused by slight vibrations of the armature as the flux field varies from zero to maximum strength with each cycle of applied voltage.

Such noises are no problem in d-c brakes. The applied voltage is unidirectional and the field does not vary in strength. The d-c core need not be laminated.

A second advantage of the d-c brake is its higher electrical efficiency. It does not draw as much holding current as does an a-c magnet of equal size, hence I^2R losses are less. Furthermore, eddy current and hysterisis losses are present only in a-c electromagnets. Because of the small magnitude of power losses, d-c magnet is often rated at only 10 C temperature rise.

Since under de-energized conditions there is an airgap between the armature and the rest of the core, the impedance of the a-c coil is low. This results in a high inrush current. But after the armature moves to close the airgap, the coil impedance rises and the holding current drops to a lower value. This is explained by the fact that coil impedance is inversely proportional to the reluctance of the core. And, the presence of an airgap in a magnetic circuit increases the reluctance of that circuit.

The high inrush current results in fast closing of the armature. This, of course, is desirable in some applications, but is accomplished by slamming noises that are unwanted in others. Also, the slamming shortens the life of the a-c brake assembly.

A d-c magnet, on the other hand, is relatively unaffected by the impedance changes described. Holding and inrush currents are substantially the same so that slamming does not occur. However, to get extremely fast action in a d-c magnet, the coil must be designed for high initial currents. These high currents do not decrease as in the a-c coil, but exist during the entire holding period. Therefore, power consumption in a fast d-c brake may be considerably more than in an a-c brake of equivalent speed.

Customarily, the a-c magnet coil is designed on the basis of its holding current. The coil cannot handle inrush currents continuously with destructive overheating. The latter can occur if the armature does not close for any reason after voltage is turned on. Then, impedance remains low, allowing current to continue at a high value. This unsatisfactory condition cannot exist in a d-c magnet coil since current is about constant regardless of whether the armature is open or closed.

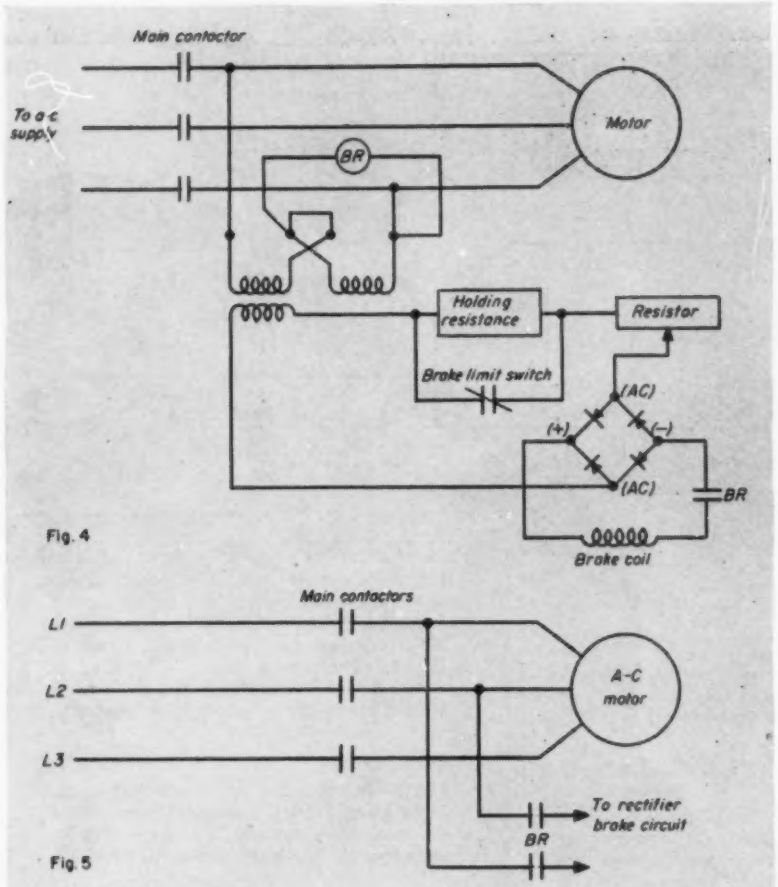


Fig. 4—Another circuit for controlling the change of voltage on the d-c brake coil. Here, the switch-over is initiated by action of a limit switch in place of the timing relay used in Fig. 2. Fig. 5—Elementary wiring diagram for connecting rectifier brake into a-c motor circuit. Power can be taken from any two wires of system.

Inrush Currents

The windings of an a-c magnet coil require careful insulation and construction. The reason for this is explained by considering the results of a shorted turn. If one turn is shorted out of an a-c coil, the remaining turns feed high currents into it by transformer action. This effect can cause dangerous overheating or, at least, a sizeable drop in efficiency. If one or several turns of a d-c coil are shorted, the result is a negligible increase in coil current. No power is transmitted into the shorted turns.

Description of Brake

The complete rectifier brake consists of a rectifier unit and a d-c electromagnetic brake assembly. One type of commercially available brake is pictured in Fig. 1. The components of the rectifier circuit are enclosed in a separate cabinet. The rectifier assembly can also be supplied for inclusion in the main control cabinet of the machine or equipment of which the brake is a part.

Control schemes vary with the manufacturer. One scheme upon which there are a few variations is shown in Fig. 2. The operation may be summarized as follows.

When power is applied relay *CR* is energized, which in turn energizes transformer. The dotted lines Y_1 and Y_2 indicate connections available for operation from a separate control source. The transformer secondary windings are series connected and furnish 220 a-c volts to the rectifier.

Upon initial power application, full secondary voltage is supplied to the rectifier input through the normally closed contacts of series relay *CR*. The full rectifier output of approximately 190 v is then applied to the brake coil.

To obtain rapid brake action, a brake coil rated at 70 v on continuous operation is employed. The relatively high voltage is temporarily placed across the coil to result in greatly accelerated build-up of coil current compared to the build-up at rated voltage. Faster brake action results.

As the coil current builds up, it reaches a value that is sufficient to operate the brake armature, releasing the spring-set brake. Further increase in current energizes the brake relay SR sufficiently for operation. When the normally closed SR contact opens, resistance RH is inserted between the 110 v center tap of the secondary and the rectifier input. The reduced a-c voltage and the insertion of series resistance lowers the rectifier input voltage, but permits sufficient current to flow to safely hold the brake in the energized (release) position.

The actual value of holding current at normal voltage has been set at 200 percent of brake magnet drop-out current at normal torque setting. The corresponding brake coil voltage at this current value is 25 to 30 v, depending upon brake size. This low value of holding voltage not only keeps magnet heating at a minimum, but also insures fast setting of the brake by minimizing the energy to be dissipated when the brake magnet is de-energized.

The current input to a brake coil is plotted against time in Fig. 3. Note that there is a slight current drop when the brake armature seals. This is the point at which the impedance of the coil rises because the core air-gap has closed. Now, impedance has no effect on steady state d-c power, but it does resist flow somewhat when the current value is rising (transient conditions).

An abrupt drop in current value occurs when the brake relay operates, cutting the coil voltage to a lower value. In the system described, the brake set time is around $\frac{1}{3}$ second. Release time varies from $\frac{1}{4}$ second to one second, depending upon the size of the brake. Larger brakes have a longer release time.

In a second scheme, illustrated in Fig. 4, a limit switch is mounted on the brake coil case. The rectifier unit is mounted separately from the brake in a ventilated cabinet.

When the main contactor is closed, the coil of contactor BR is energized, completing the d-c circuit from the rectifier. This causes activation of the brake coil. During the starting period, a limit switch mounted on the brake short circuits the holding resistance. Thus, when the motor is started, full voltage is applied across the brake coil, immediately releasing the brake shoes.

When the brake plunger reaches the bottom of its stroke, it mechanically opens the contacts of the brake limit switch. This action inserts resistance in the circuit and lowers the current through the brake coil to a safe operating value. Opening the main contactor automatically causes the brake to set by de-energizing relay BR. This opens the brake coil circuit, allowing spring action to shift the armature.

Application

The rectifier-operated brake may be operated by single phase power obtained directly from two motor terminals as shown in Fig. 5. Thus, the brake is released when power is applied to the motor, and set when the motor is shut down. As an alternative, the brake relay can be connected to a control source. Then, when the motor contactor is energized, the brake is released.

Naturally, brake operating time must be considered. This is particularly true when the brake is used with an across-the-line motor. This is because the motor is stalled under full power while the brake is being released. This results in extra heat being developed in the motor windings. Consequently, the rectifier operated brake should not be applied when this type of motor is to be frequently started, unless a time delay device or an additional series relay with normally-open contacts in the brake coil circuit is used. In this way, the control can be made to energize the motor at the exact time of brake release.

This does not apply to slip ring motors with external resistors for speed control. In this type of motor, the added resistance is in the circuit on the accelerating positions of the controller. Since starting current is limited, negligible extra heat is developed while the brake is being released.

Brake release time for one manufacturer's product varies from approximately ¼ second on a 10 in. brake to less than one second on a 26 in. brake. It takes less than 0.2 sec for either brake to set.

Initial energization power input for the same 10 in. brake is approximately 800 volt-amperes, while for the larger size brake 1,250 v-a are required. Holding values are considerably less, being 185 v-a for the smaller brake, and 290 v-a for the larger.

Specific Uses

Most brakes used with rectifier units are spring-set and magnetically released. The brake and rectifier units may be employed on cranes, hoists, turntables, conveyors, and other types of rotating machinery.

One application of a rectifier brake is on a wire block and spooler. These two distinct machines which in combination first draw wire down to successively smaller diameters through a series of dies, and then automatically wind the finished product on spools. Between each of the dies is a driven spindle, around which the wire is wrapped to provide the tension needed to pull the wire from the previous die. After the wire is drawn through the last die, it is wrapped around the end spindle of the wire drawing machine. From the wire drawing machine, the wire is fed through a storage system into the spooler machine for the final spooling operation.

In Fig. 6 is shown a typical brake circuit for the main motor in this application. When the jog button is depressed, coils JR and BR are energized. Relay JR has contacts in the main motor circuit to start the motor. At the same time, the BR contact in the brake circuit energizes the brake coil, causing the brake to open. Releasing the jog button opens the BR circuit, causing the brake to set once the BRT relay has timed out. This opens the JR coil circuit, cutting off power to the motor.

In most cases, the machine is jogged only during the set-up operation. For short jogging operations, the brake need not set since the speed does not build up appreciably and the friction load is enough to stop the machine quickly. Accordingly there is no need to cause additional brake wear by making the brake set on a moving shaft. The brake is held open through the BR holding contact and the closed contact of the BRT timing relay. For longer jogging operations where the speed builds up appreciably, stopping

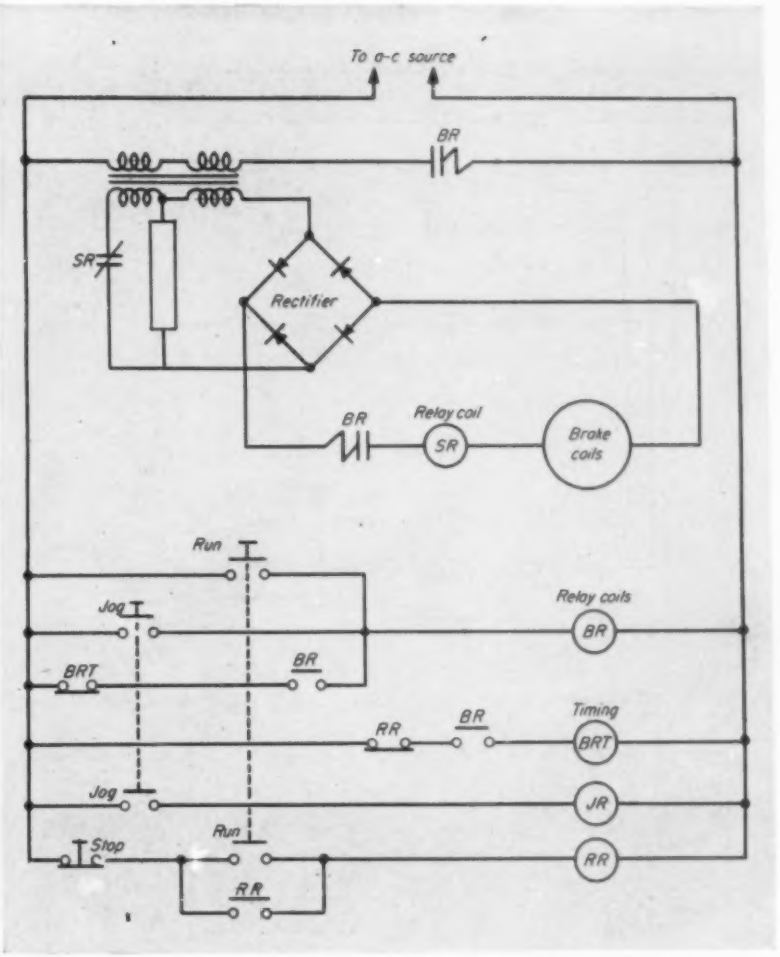


Fig. 6—Control circuit for wire spooling machine. This circuit has an interesting braking arrangement during jogging. By means of a timing relay, the brake coil is kept energized during intermittent pressing of the jog button. This makes for faster action and reduces wear on the brake lining and mechanism.

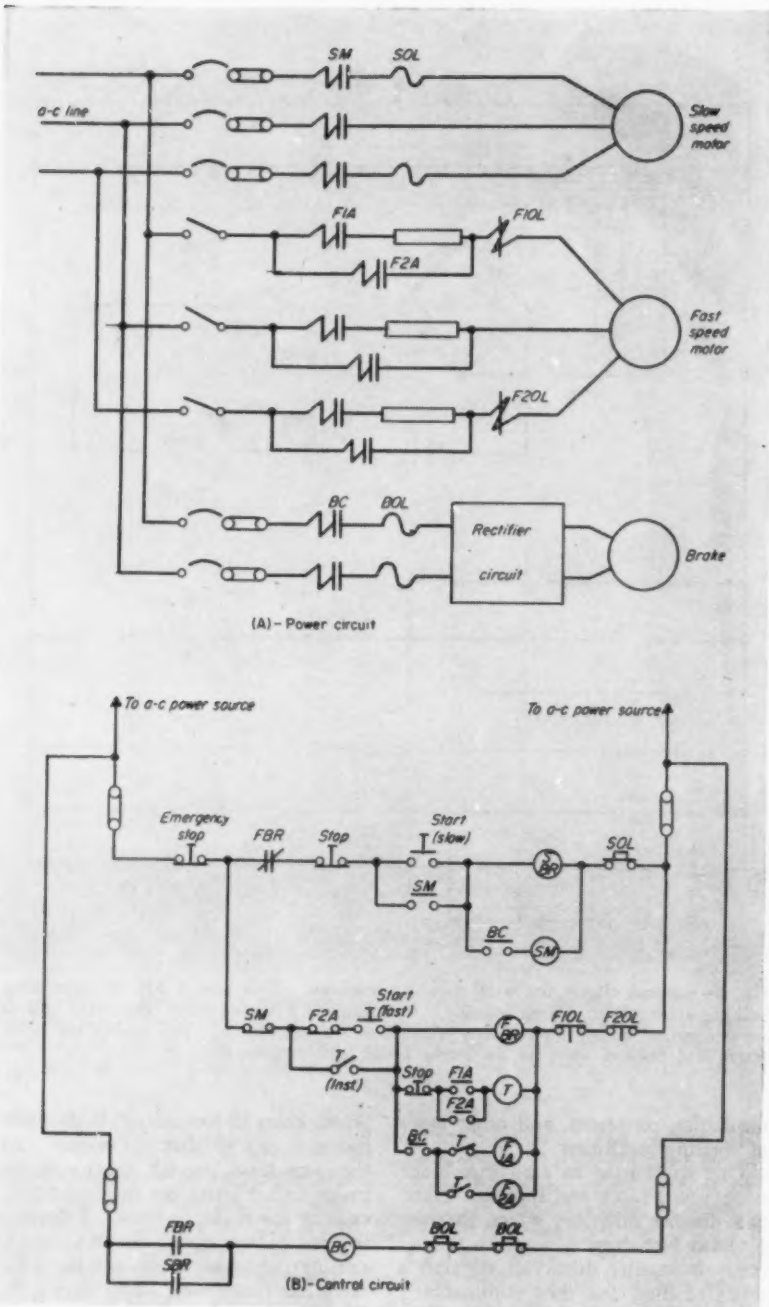


Fig. 7—Application of the rectifier brake to a conveyor drive motor. This circuit is unusual in that a separate contactor is used for the rectifier brake. Thus, either motor can be removed from the system without disturbing operation of the other.

is accomplished when the jog button is released by friction load plus brake action. In this case, the BRT closed contact opens, causing the brake to set immediately after the jog switch is released.

When the run button is pressed, relay BR is energized and the brake opens as before. In this case, the contacts of relay RR energize the main motor. Relay BRT cannot start timing out since its coil is opened through the normally closed contact on relay RR. Accordingly, after the initial energization by the run button, the relay BR is held closed through the BR and BRT contacts.

To stop the mechanism, the stop button is pressed opening contacts RR and allowing relay BRT to time relay BR out of the circuit, thus permitting a delay in application of the brake. The delay in stopping the main motor is required on run since stopping this drive must be delayed until the high inertia spooler is stopped, otherwise snapping of the wire would result. In jogging, however, a quick stop is permissible. The reason for this is that in jogging the operator is generally threading the wire through the dies, the spooler is not connected and the speed is not great.

The need for a brake capable of highly repetitive operation with low maintenance expense was apparent here, and a rectifier brake was selected for this application.

Conveyor Drive

Rugged construction is required on a screening machine used to separate coke into various grades. The conveyor drives for this machines are subject to considerable vibration and operates in extremely dusty atmosphere. Rectifier brakes were selected since they are less susceptible to service difficulties.

The circuits for the conveyor drive motors are shown in Fig. 7. Two motors are employed on each conveyor, one for fast speed and the second for lower rates of conveyor travel.

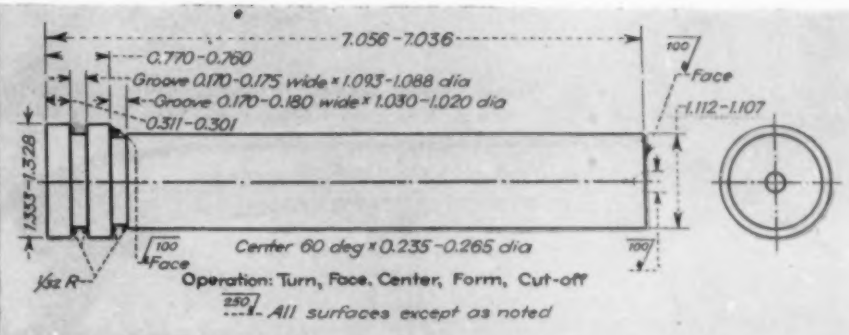
The power circuit depicted is somewhat unusual in that a separate starter for the brake is employed. This allows for greater maintenance flexibility, since either motor can be detached from the line for maintenance purposes. Note that in this case one brake is used for two motors, because both motors are mounted on the same shaft.

The control circuit is fairly simple. Pressing the Start (slow) button energizes coil SBR. A contact on SBR closes the brake contactor coil circuit (BC), and release the brake. A contact on BC energizes SM and the slow speed motor starts.

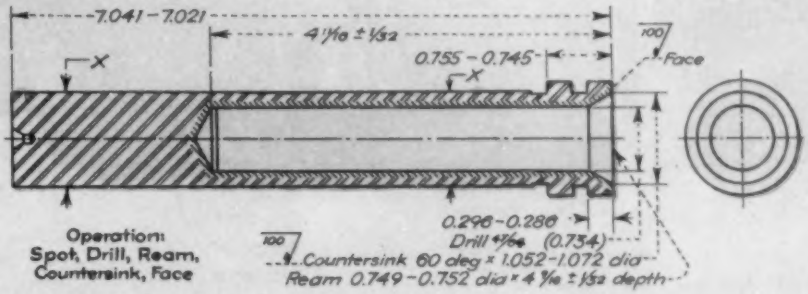
When a faster speed is required, the stop button must be depressed. Pressing the Start (fast) button energizes FBR which also has a contact in the BC coil circuit to release the brake. F1A is energized and the motor starts on reduced voltage. Timing relay (T) times out and energizes F2A while opening F1A thus applying full voltage to the motor.

Depressing the stop button opens FBR and F2A causing the brake to set and the motor circuit to be opened. Note that when switching from slow to fast an interlock on FBR opens the SBR circuit which in turn cuts off the power to the slow speed motor. To get back to slow speed, the stop button must first be depressed. Note that automatic electric braking eliminates another operator responsibility.

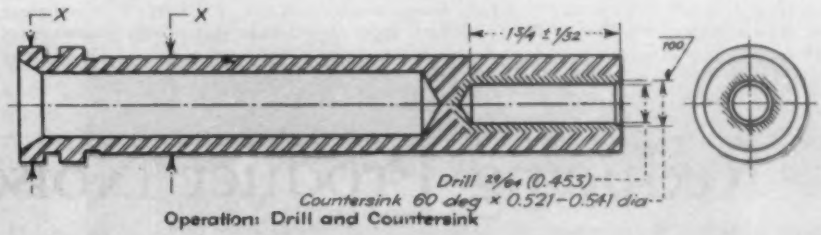
Department: Turret
Maintain all diameters and center concentric within 0.005 in. full indicator reading.



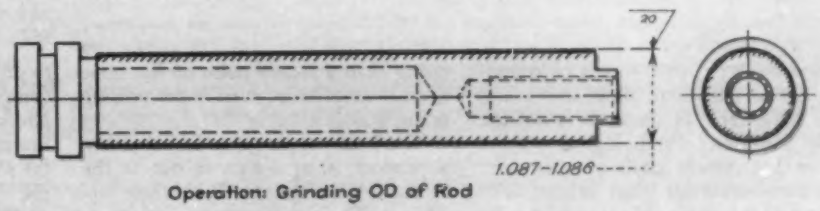
Department: Turret
Maintain countersink concentric with x dia. within 0.005 in. full indicator reading. Maintain 0.749 in. dia. and x dia. concentric within 0.007 in.



Department: Turret
Maintain countersink and drill concentric with x diameters within 0.005 in. full indicator reading.



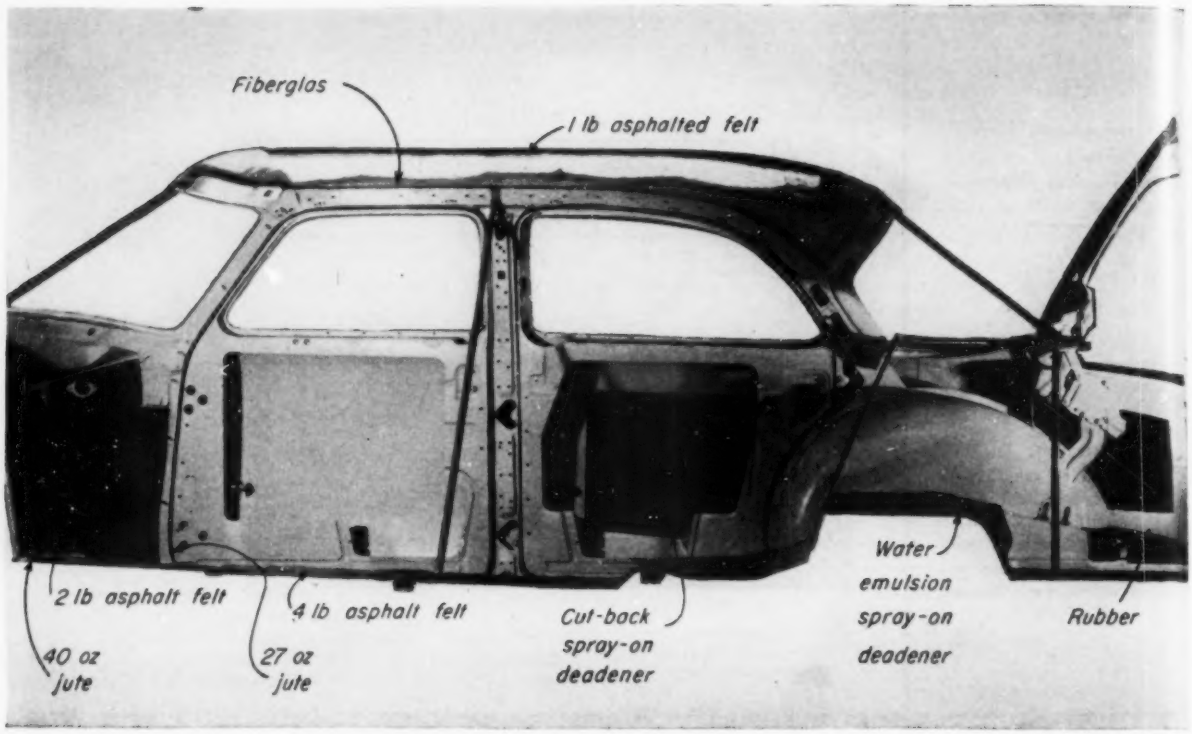
Department: Grinding
Maintain 1.087 in. dia. concentric with centers within 0.001 in. full indicator reading.



Streamlining Production Drawings

To save production time and also eliminate costly errors that result from misreading blueprints, Electrol, Inc. has obsoleted the conventional method of making production drawings. Instead of crowding on a single sheet all the dimensions and other data required to machine and otherwise produce a specific part, a separate drawing is made for each operation. Only the information necessary to perform that particular operation is given on its corresponding blueprint.

Shown above are typical examples of these modified drawings. These four represent about one-third of the drawings, and the respective operations, required to produce a hydraulic piston. The designated departments and notes at left also appear on the drawings.



Ford Motor Company

Fig. 1—Nine different acoustic materials help deaden the noise in the 1952 Ford: 1 lb asphalted felt (roof); 2 lb asphalted felt (side cowls); 4 lb asphalted felt (floors, dash); cut-back spray-on deadener (doors, rear quarter-panel); water emulsion spray-on deadener (wheel wells); one-inch, half-pound fiberglass (roof, dash); 27 oz jute (front floor); 40 oz jute (front toe-board) and rubber mat.

Reducing Product Noise With Acoustic Materials

NOISE IS ANY SOUND that is objectionable at a particular time and place, and noise level or loudness is not the only criterion. Psychological studies show that certain kinds of noises are more objectionable than others. For instance, the most objectionable noise to the human ear is a high frequency sound above 500 cps. And when a high frequency sound is heard in combination with a low, the low masks out the high so that it is often missed in the first study. But even though apparently unheard, the high frequency sound is a source of irritation. If only the low frequency sound is treated when this condition exists, the acoustically treated product may appear noisier than the original.

Erratic noise is harder to tolerate than a rhythmic sound of the same pitch and loudness. Pulsed noises like repitative hammering are more irritating than a steady noise of the same average amplitude; even if the pulsing is rhythmic.

The best way to get rid of noise in a product is to design it out at the source of excitation. But where redesign for acoustic improvement is not practical, designers can often reduce noise to a tolerable level by the proper use of acoustic materials.

Using Acoustic Materials

Noise reduction with acoustic materials is still done on a trial and error basis, and a good treatment is usually the result of several minor improvements. The effectiveness of an acoustic material depends not only on its inherent sound reducing properties but also on how and where it is placed. In general, designers follow this plan: (1) use absorbers to reduce the noise within a compartment; (2) use insulators to prevent noise from moving from one compartment to another; (3) use isolators to prevent the conduction of vibrations; (4) use deadeners to reduce the singing or drumming of large panels.

Absorbers are materials that reduce the sound already in a chamber by preventing its reflection. They convert sound energy to heat to reduce the noise level inside a compartment while permitting the transmission of some sound. Conversion may occur in two ways: dissipation of sound by friction forces, or transformation of sound into heat by viscous forces brought into play when sound is propagated through the materials.

Insulators are mechanical barriers that block the pressure changes that make up the sound waves, and their main purpose is to prevent noise from leaving a chamber. They do not re-

duce the internal noise level by any appreciable amount.

Resilient isolators get rid of noise where vibrating parts join a structure. They prevent the structure from acting as a sounding board, and may work in either of two ways: by absorbing the vibrational energy through deflection of the isolator, or by converting the energy into heat through internal friction of the material without deflection.

Drumming or singing of large unsupported panels that are loosely coupled is reduced by sound deadeners or dampeners, that add friction to the oscillating circuit and break up natural vibration frequencies. However deadeners will not work on panels that are under forced excitation. They will not replace good vibration insulation nor will they cure rumble due to poor design. The latter can be corrected only by proper bracing.

Absorbers

Absorbers are widely used acoustic materials because they are efficient at reducing objectionable high frequency noises. And commercial suppliers make a large variety of absorbing materials that can be applied to any kind of product. They are usually loose fibrous materials so that sound waves cause these light fibers to move and rub against each other and the friction of rubbing changes the sound into heat. As a result the sound is dissipated instead of being reflected.

A large number of substances and combinations of ingredients have successfully been used as absorbers. These include: vegetable fibers like wood, jute, bogasse, and cotton; hair felt; mineral fibers such as asbestos, glass, and mineral wool; and aggregates like pumice, vermiculite and perlite. The bonding agent used with these materials also affects sound absorption and foaming agents are often added to increase porosity.

These materials are available in several forms: (1) prefabricated materials, (2) plasters, and (3) sprayed-on materials. Selection depends on cost, appearance, maintenance, service conditions, and method of application.

The last item is important because how the absorber is affixed to the product affects the amount of sound absorption. These methods are generally used: absorbers may be cemented directly to the product; they may be nailed; or they may be sprayed on.

Acoustic adhesives made especially for cementing sheets of absorbing material are available. In addition, the same cements used with heat insulation can be used with acoustic absorbers. These are particularly useful when the absorbing material is subjected to temperatures above 200 F. The acoustic cement must meet the same service requirements as the absorbing material. For example, it may have to be fireproof, have a certain vapor pressure, be vermin-proof, etc. While this is a common method of affixing absorbers, cements should not be used on a surface that sweats. Also there is one acoustic objection to this technique. When an absorber is cemented to a product there is no airspace left behind it. Measurements show that the absorbing qualities of an installation are improved if such an air space is present. This is particularly true when absorbing low frequency noises.

Fig. 2—Ford Motor Company's Engineering Staff developed this 225 lb "listening" mechanism for acoustic studies. Ford test engineers mount mechanism in rear seat of automobile and suspended microphone (center) picks up all noises entering car's interior. Tape recording instruments gives permanent record of any noise as a check report on continuing improvements. Engineers ride thousands of miles yearly, on all types of roads, in order to get complete "noise record" of modern automobile.

Airspaces can be set up by nailing sheets of the absorber to structural members. This constrains the material at some points more than at others so that sound waves set the absorber into flexual vibrations that are damped by friction between the fibers. Fibrous materials like felted asbestos, wood and glass fibers exhibit this additional sound absorbing properly which is called diaphragmatic absorption.

Asbestos and mineral wool materials can be applied to a product by spraying the shredded fiber, with a suitable binder, directly on the surfaces to be acoustically treated. After spraying, the material is rolled or tampered to a smooth surface. The absorbing quali-

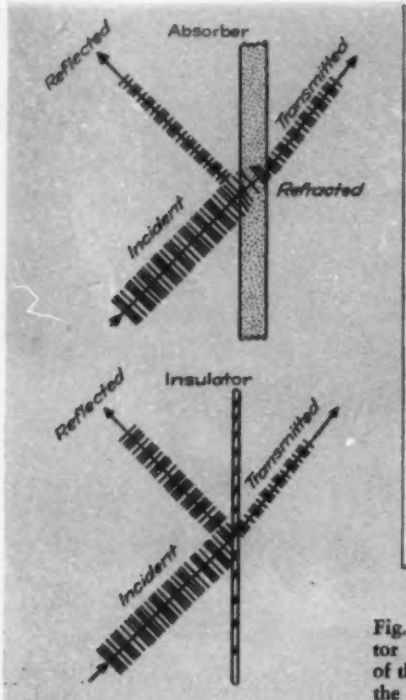


FIG 3

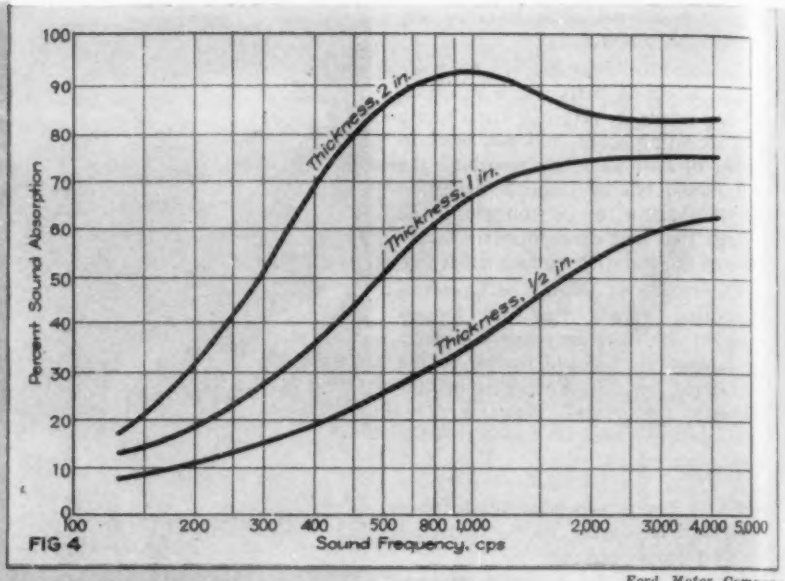


FIG 4

Ford Motor Company

Fig. 3—Schematic diagram illustrates how an insulator and absorber work. The insulator reflects the greater portion of the sound energy; while the absorber converts most of the sound energy into heat. Fig. 4—Typical absorption curves for spun glass indicate the effect of increasing absorber thickness. Curves also show absorbers' ability to

ties of sprayed-on materials depend on the porosity and thickness of the coat.

Main disadvantage of spraying acoustic materials is their structural weakness when applied too loosely or with insufficient binder. Also, vibrations may shake the fibers loose. However, they are used widely where appearance is an important factor because they can be painted repeatedly with a water base paint without losing much of their sound absorbing properties.

Acoustic plasters are used when a broad area requires acoustic treatment. However, plasters must be applied by expert craftsmen to obtain rated sound absorption coefficients. The mix proportions and the recommended mixing time must be adhered to strictly; the surface requires stipling to prevent a glazing which disrupts their ability to absorb noise; and the surface texture must be produced at the correct time and to the exact degree.

High temperature areas can be treated with ordinary acoustic absorbers providing they are protected from the heat by layers of heat insulating materials. These materials act as a thermal break, but because of their fibrous construction also help absorb the noise.

Since their purpose is to prevent reflection, the absorber should cover as much of the chamber's surface area as possible. Any uncovered area will bounce the sound back and forth and diminish the effectiveness of the acoustic treatment. Noise reduction can be increased by increasing the thickness of the absorber, Fig. 4. However, even a thick absorber covering only a small amount of surface area will have little or no beneficial effect.

Sound reduction properties of absorbers can be compared in a room that is free of disturbing noises. To make the test, the reverberation time of the room is first measured. This is the time required for a sound of a known level to reach a specified lower level. The absorbing material is then placed around the room and a new reverberation time is measured. The shorter the reverberation time, the better is the material as an acoustic absorber. The construction industry is a big user of absorbing materials, some of which are slightly different than those described above. For example, some acoustic tile has many holes drilled in it to increase its absorption of sound waves. The sound, instead of being reflected back into a room, enters these holes and is reflected inside the hole until it is dissipated. Cloth drapes are another popular absorber in this industry.

Most economical treatment usually makes the absorber perform more than its sound reducing job. In automotive design, car upholstery has an accoustic and appearance function.

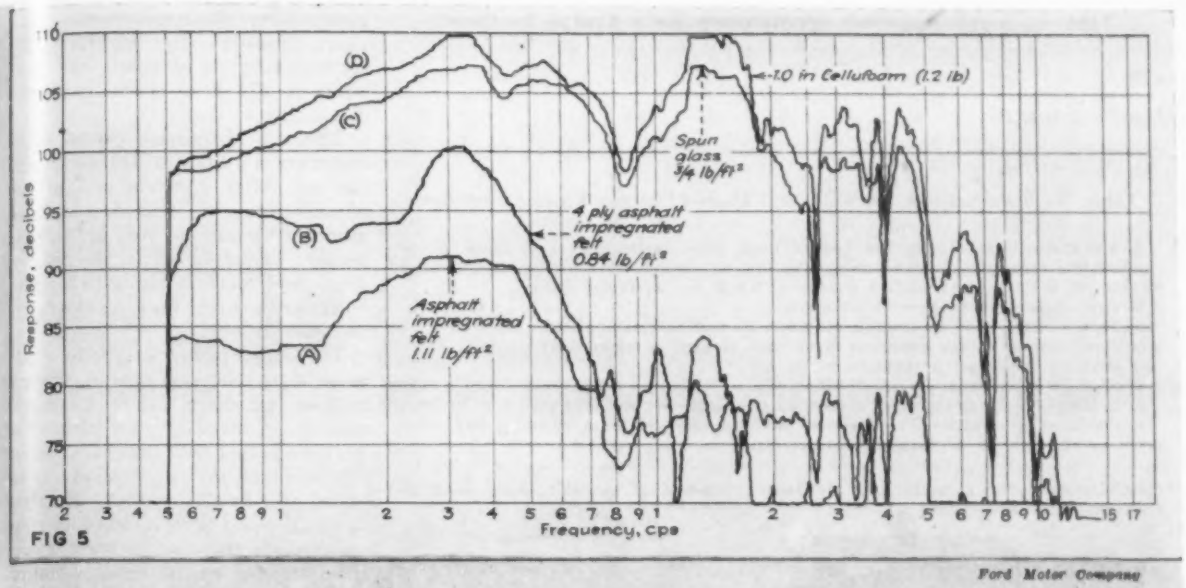
Insulators

Although often confused with acoustic absorbers, insulators perform an entirely different function. They contain noise in a chamber without reducing the internal noise level appreciably.

As mechanical barriers, insulating materials are dense, massive and impervious to air. They must also be stiff so they do not act as diaphragms and set up secondary noises. In general the heavier a material is the better an insulator it is. Since they act as a bar to the passage of sound waves, any opening in an insulator drastically reduces its effectiveness and openings are the chief problems in using these materials. If the design requires an opening for wires, piping or ducts, a seal should be used around the opening to maintain the insulation effect, and an acoustic filter should be placed in ducts and large pipes.

Materials used as acoustic insulators include: steel, wood, thick rubber mats, lead, linoleum, asphalt impregnated felts, and heavy dense fiber paddings. Selection depends on: degree of noise reduction desired, cost, availability, ease of fabrication and installation, weight limitations, and service conditions.

For example, lead is an excellent acoustic insulator because of its density. But its weight, and lack of struc-



deaden high frequency sounds. While increasing the thickness of the absorber improves noise reduction, economic and production factors may limit the thickness that can be used in a specific application. Fig. 5—Results of Sound Transmission Tests in sound tunnel indicate comparative value of these materials as acoustic insulators. The dense (1.11 lb/ft²) asphalt felt is the best insulator of these four materials. Response indicates noise level after insulator.

tural strength limits its use. In an automobile, a heavy steel insulator between the engine compartment and the car interior would make for quieter riding by keeping engine noises out of the car. But the cost, weight, installation and heat transfer problems make it impractical when compared to a material like asphalt-impregnated felts.

Gear boxes are a source of noise that are particularly well suited for treatment with insulators. Since many of these are already enclosed by metal for safety reasons, it is easy to reduce gear noise by increasing the thickness of the enclosure and sealing around shaft openings.

For reasons of economy and weight saving, designers often combine layers of insulating materials. Two such popular laminations are steel or aluminum lined with linoleum, and alternate layers of asphalt impregnated felts and fiber pads. Usually, as long as the lamination is impervious to air, it will have some beneficial effect as an insulator.

Studies in a sound test tunnel will produce data for comparing insulating materials by measuring the transmission loss through them. The tunnel is a rectangular wooden box that is lined with absorbing material; one end is open and has a loudspeaker facing out of the box. The insulator to be tested is placed against the loudspeaker so that it seals the tunnel.

Sounds of a measured intensity and varying frequency are played through the loudspeaker and picked up by a microphone, after they have passed through the insulator. They feed into a sound analyzer, a sound level meter and a Brush recorder to produce a graph of intensity versus frequency (Fig 5). This indicates the transmission loss in decibels, the difference between the sound level at the source and the level outside the insulator. A good insulator has a big transmission loss over a wide range of frequency.

Usually the first step in attacking a noise problem is to try to isolate the noise with an insulator, or to reduce the noise level with absorbers. So absorbers and insulators are sometimes used interchangeably with unsatisfactory results. The designer can avoid this by remembering that insulators do not reduce the internal noise level appreciably; but they do cut down the transmission of sound. Absorbers do reduce internal levels; but they transmit an appreciable amount of the noise outside the compartment.

Absorbers can be used in combination with insulators to increase the effect of a limited amount of absorbing material. In this case, the absorber is backed up with a good insulator which reflects the noise back through the absorber. This gives the effect of twice the thickness of absorber and at the same time reduces the intensity of the noise being transmitted outside the compartment.

Also acoustic insulators and absorbers are often confused with thermal insulators and absorbers, primarily because of a carryover of nomenclature. It is common to recommend and advertise a material as a good "thermal and acoustic insulator." What is meant is that the material is a good thermal insulator and a good acoustic absorber. Because of their porous fibrous composition sound absorbers make good heat insulators and the two can be used interchangeably, but sound insulators make poor heat insulators.

Isolators

In general, the more a material deflects, the better an acoustic isolator it is. Materials commonly used are springs (for light members), felt, natural or synthetic rubber and neoprene. They are placed as close to the source of vibration as possible.

However, the use of these materials does not guarantee a good isolation job. The machine must be designed so that the isolators are not bypassed and vibrations transmitted through other members that are rigidly connected to the vibrating part. Isolators with incorrect properties provide no benefit or make the noise worse.

Isolators have other important jobs

Table I—Sound Reduction Specifications for a Typical Insulator

CPS	100	200	400	600	800	1000	2000	3000
Loss Factor Decibels	90	93	93	85	80	78	73	72

Table II—Specifications for a Typical High Efficiency Fluid Dampener

1. Vibration decay—Using the Geiger thick plate method, over a range of 60 decibels, the decay time shall be no greater than 60 seconds over a temperature range of from 30 to 90 F for a surface density of 0.5 lb per sq ft dry weight.
2. Cold Adhesion—85 percent retention.
3. Sprayability—Shall be suitable for use with commercial applicators, and produce a uniform coating with a minimum spray back of sand or other solid particles. Flow rate shall be one quart per minute.
4. Sag—¼ in. maximum at 0.5 lb per sq ft.
5. Settling—The material shall not settle or separate out within a period of 30 days.
6. Chemical Resistance—The material shall be impervious to cleaning and other solutions encountered in usual manufacturing.

Specifications cover a mastic type deadener composed of Asphalt Clay, Asbestos, Limestone resin and solvent.

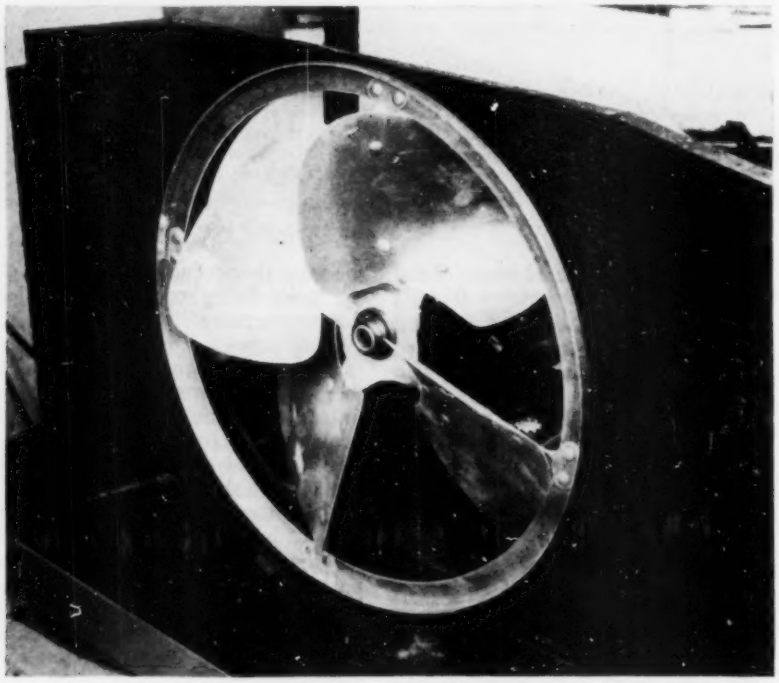


Fig. 6—Mastic sound deadener sprayed on the panels of this home air conditioning unit prevent the panels from acting as a sounding board for fan vibrations.

in addition to noise reduction and their design and functioning has been covered extensively in previous articles (PRODUCT ENGINEERING: April '49, p 86, Feb. '50, p 104, Dec. '50, p 130, Dec. '50, p 167).

Deadeners

Two kinds of deadeners are used: solid materials—like waffled felt, jute, sheet mica and sheet lead—cemented to the panel, and mastic coatings applied to the panel.

Because of their easy application, mastics are being used more extensively. They can be sprayed, rolled, troweled, flowed or brushed on. Basically they may be considered as sand particles suspended in tar and there are two types: emulsion and cutback. The emulsion mastic uses water as a solvent while the cutback uses an inflammable solution. The latter has better stability, adhesion and will not freeze. But the emulsion type is necessary in applications where a fire hazard prevents the use of inflammable materials. Table II lists typical specifications for a high efficiency dampener.

Panels that are dampened by mastic coatings require no special pre-treatment. They don't even have to be clean. However, after application the coatings have to be baked for three hours at 275 F to obtain maximum dampening.

Tests on dampened panels* show that there is a limit to what deadeners can do. After a certain area of the offending panel is treated, additional deadener produces no appreciable benefit. Therefore tests in the product define how much deadener to use and no more is used than is absolutely necessary.

The Geiger plate test (conducted in an ordinary room), is used to compare relative deadening values of mastic coatings. A standard steel plate, that has been coated with the mastic in accordance with test specifications, is vibrated at a fixed frequency. A vibration pickup and timer measure the time required for the plate to reach a specified reduced amplitude of vibration after the oscillation excitation has been removed. Shorter times mean better dampeners.

Test Equipment

Because the human ear is an unreliable device for comparing sounds, instruments are used for all measurements. For instance, the Ford Motor Company engineers record car noises with a tape recorder under identical conditions before and after acoustic treatment. They play back the tapes in the laboratory and make measurements to verify the improvement.

The basic instrument for this measurement is the sound level meter which measures the intensity of sound in decibels, a logarithmic ratio of that sound to an arbitrarily selected sound. This device is a must in acoustic work.

Table III—Equipment for Acoustic Testing

MINIMUM EQUIPMENT

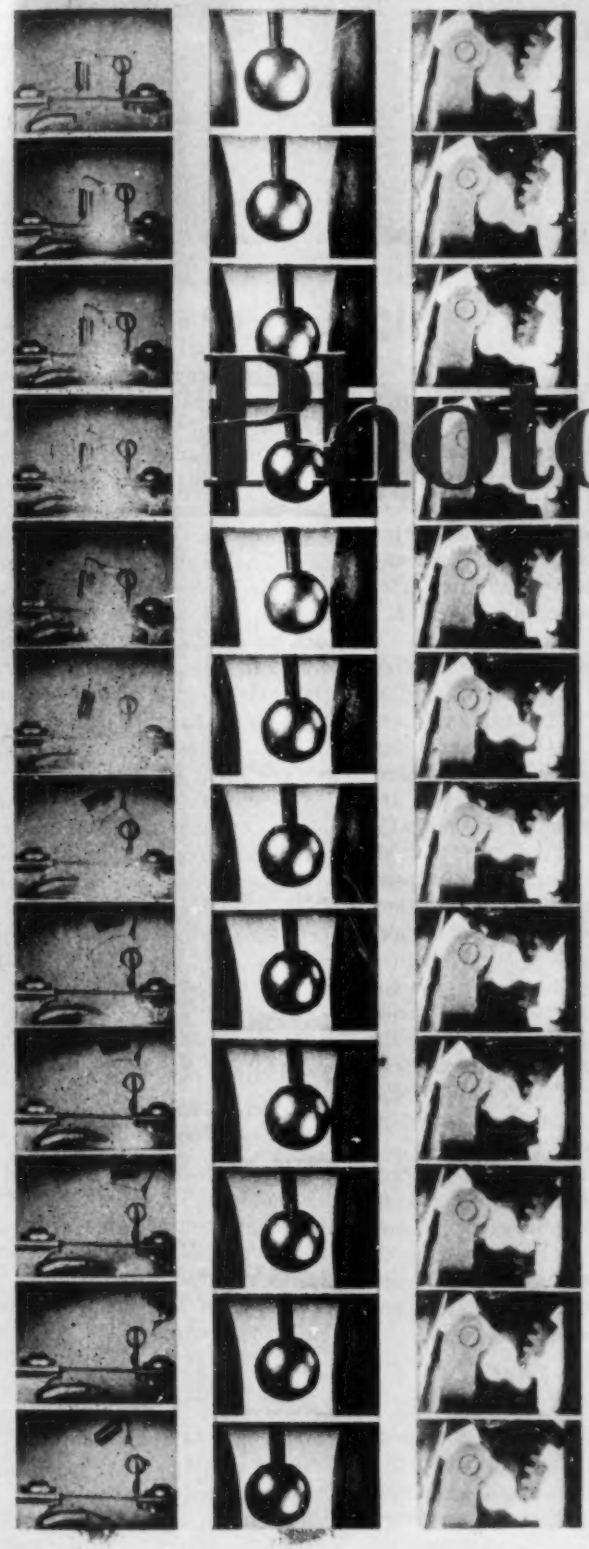
1. Sound level meter
2. Sound Analyzer
3. Stroboscope
4. Stethoscope

FOR THE COMPLETE LABORATORY

1. High Fidelity magnetic recorder
2. High Speed level Recorder
3. Vibration analyzer
4. Fastox Camera
5. Good loudspeaker

MORE ELABORATE EQUIPMENT

1. Vibration meter
2. Sound level Response Recorder
3. Cathode Ray Oscillograph
4. Magnetic Recorder
5. Beat Frequency Oscillator
6. High Quality Microphone
7. Audio Amplifiers
8. Electronic Voltmeters



High Speed Photography in Design

C. DAVID MILLER
Battelle Memorial Institute

KENNETH SHAFTAN
J. A. Maurer, Incorporated

Basic Considerations
Cost of equipment
Event duration
Types of photographic record
Determination of repetition rate
Choice of exposure duration
Establishment of time scale

High Speed Cameras
Basic operation
Characteristics of major types

Typical Fields of Application
Knock in piston engine
Atomization for spray drying
Vibration in structures
Fluid flow through impeller

PRODUCT ENGINEERING
September 1952

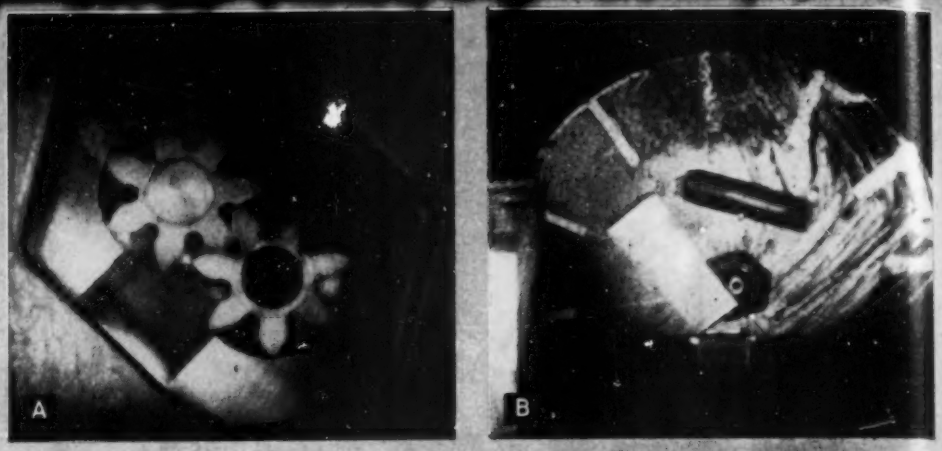


Fig. 1. The duration of an event being studied is classified as either extended or limited. Rotation of pump gears (A) represents an event of extended duration—movement with high translational velocity. The instantaneous fracture of an armor steel izod-notched finger (B) under impact of a projectile illustrates an event of limited duration—a rapid, inherent change with time.

NAVAL RESEARCH LABORATORY (IRWIN & HAVVER)
GULF RESEARCH AND DEVELOPMENT COMPANY (FOOTE)

What Is It?

When used to observe and record simultaneously dynamic phenomena, high-speed photography is a versatile and valuable tool. It not only offers the designer all of the advantages generally associated with ordinary stills and moving pictures, but it also puts at his disposal a means for actually studying motions and events that until recently have never been "stopped" or slowed down to perceptible speeds. This is particularly true of transient or nonreproducible phenomena.

Of great importance in dynamic experiments is the fact that photography of a moving part does not alter its mass, nor affect the forces acting upon it, and thus does not influence its motion under the action of accelerating forces. The camera has no intelligence, hence conclusions derived from information so obtained depend only upon the experimenter himself and are not "colored" by observations of an intermediate human observer.

High-speed photography offers a powerful method of research and development, able to cope with rapid physical changes of which there are four basic types: (1) linear motion, such as a rocket in flight; (2) rotational motion, like a revolving gear; (3) growth or shrinkage of an object, such as the deformation of an aircraft tire under the impact of landing; and (4) homogeneous changes throughout an object, as in the autoignition of a homogeneous mixture of combustible gas and air while being compressed.

Data obtained with a high-speed camera are both quantitative and qualitative: quantitative when the purpose is to determine the exact velocity of a motion already known to occur; qualitative when the aim is to discover changes or motions not already recognized. The results of qualitative photography are often of great value in that they may lead to quantitative evaluation after motions or changes are revealed.

High-speed photography is a means for *arresting* or *retarding* the motions of rapid events so that they can be understood and analyzed. The results are an *expansion in the time base* or *time magnification* relative to other factors involved in the event. Time magnification is equal to the rate at which motion-picture frames are exposed divided by the rate at which they are later projected. Time magnification is the opposite of the effect produced by the "time-lapse" photographic technique, wherein a series of pictures is exposed with long time intervals between frames. Here the result is a *compression of the time scale* and an apparent speed-up of the event upon projection.

The term "high-speed photography" therefore includes the taking of pictures with short exposure durations, as well as at high rates of repetition. The term is usually applied only when the exposure duration is less than one millisecond.

What Does High-Speed Photography Cost?

The cost of high-speed photography is largely determined by the number of frames required in one "burst", the shortness of exposure desired, and the required repetition rate or number of frames exposed per second. A fourth factor that influences overall cost is the complexity of the phenomenon under study.

The principal expense item is apparatus. Equipment for single high-speed frames may cost from $50 to $5,000, whereas equipment for large numbers of images at high repetition rates may cost $1,000 to $100,000. The simpler, commercially available, high-speed motion-picture cameras and accessory equipment such as lights, stands, speed controls, and lenses may require an initial investment of $2,000 to $8,000. On the other hand, operational costs for film, processing and printing average about $10 per run.

The repetition rates needed in the solution of many practical problems sometimes exceed those attainable with high-speed cameras commercially available. Since equipment costs for producing such repetition rates would be prohibitive for many potential users, the complete facilities at centralized research and development laboratories can be engaged at a reasonable cost.

Who Should Take High-Speed Photographs?

In many instances, personnel of the photographic department in an industrial plant or research laboratory can take high-speed photographs satisfactorily. But as the complexity of a problem increases, the project engineer is consulted.

In recent years, as the applications of scientific photography have become more widespread, a new member of the research team has come into being: the specialist in photographic instrumentation. He should have the scientific background necessary both to understand the uses and limitations of

photographic instrumentation, and to comprehend the nature of the physical problem.

Where Can the Product Engineer Learn More About High-Speed Photography?

Most of the published data are in the scientific and technical periodicals, particularly the *Journal of the Society of Motion Picture and Television Engineers;* Section B, Photographic Technique and Science, *Photographic Society of America Journal; Photographic Engineering*, the journal of the Society of Photographic Engineers; Section B, *Journal of the Royal Photographic Society of Great Britain;* and the French digest publication, *Sciences et Industries Photographiques.* Additional data appear from time to time in many of the scientific and technical journals throughout the world. The Society of Motion Picture and Television Engineers and the Society of Photographic Engineers conduct semiannual or annual symposia on high-speed photography and related subjects. The few available books on this subject are listed in the Bibliography at the end of this article.

Basic Considerations

Translational speeds for common events covering the entire range from one fps up to the speed of light are shown in Table I. In observing events, whether they are of extended or limited duration, Fig. 1, the need for time magnification by high-speed photography and the degree of the needed time magnification are determined by three elements: (1) The distance through which the motion of the object can be observed at a velocity constant in both magnitude and direction, (2) the speed of the object, and (3) the dimensions of the object.

The degree of the needed time magnification varies inversely with the distance through which the movement can be observed, and directly with the speed of the movement. Unavoidable limitations of the distance through which a movement can be observed may be the fact that the motion continues in one direction through only a short distance, or that the position of the observer is close to the path of the moving object. The latter condition causes the movement to become nearly parallel with the line of sight within a very short time interval.

Small dimensions of the moving object limit the distance at which the movement can be observed. They can, therefore, be an indirect obstacle to visual observation when the first two limiting elements are not inherently too serious. Small dimensions may require repetition rates in excess of those dictated by a desired time magnification, in order that "jumping" of the object on the projection screen can be avoided. Also small dimensions of moving objects necessitate exposures of short duration.

The slowest of the events in Table I, the turning of cast iron in a lathe, cannot be studied easily by eye. Though the speed of one foot per second is low, accurate observation is limited by the small dimensions of the chips, and the shortness of the distance through which the chips move with constant speed and direction. The same considerations prevent visual observation and study of most of the other events in the lower ranges of velocity shown in Table I. Motion of the automobile at 44 ft per second, however, can be clearly observed by a man standing at an appreciable distance from the road. Moreover, the movement of stars through space at speeds of 10^6 ft per sec are much too slow to observe by eye. This motion

Table I—Velocity Scale for Common Events of Extended Duration

EVENT	Approximate velocity, ft per sec	Order of velocity, ft per sec
Roughing cut on hard cast iron in lathe	1	1
Roughing cut on soft steel in lathe	8	
Drawing of fine copper wire	17	
Surface movement of small internal grinder	35	10
Automobile at 30 mph	44	
Leather belting in power transmission	35–130	
Band saw cutting wood	130	
Surface movement of Bakelite grinding wheel	150	
High-speed steel belting in power transmission	300	10^3
Flame propagation in combustion chamber of piston engine	50–500	
Peripheral movement of high-speed rotating machines such as centrifuges, high-speed-camera drums and supercharger impellers	500–1,000	
Jet fighters in flight	900–1,100	
Sound in air	1,000	
Bullet in flight	2,600	10^3
High-velocity projectile	3,300	
Development of a crack in glass	5,000	
Development of knock in spark-ignited piston engine	4,500–7,000	
Detonation of high explosive	9,000–25,000	
Leader stroke of lightning discharge	33,000	10^4
Expansion rate of fuse wire on violent overload	50,000	
Motion of earth around sun	100,000	10^5
Movement of meteors in space	130,000	
Movement of faster stars through space	1,000,000 –5,000,000	10^6
Orbital motion of electron in hydrogen atom	10,000,000	10^7
Main stroke of lightning discharge	33,000,000	
Electron after acceleration through 10,000 volts	100,000,000	10^8
Light	980,000,000	10^9

can be determined only from photographs taken at intervals of months or years, or spectroscopically if the motion is in the line of sight. This phenomenon is an extreme example of the advantages of a distant viewpoint, the great distance through which motion continues with constant speed and direction, and large dimensions of the moving object. The principle illustrated by this example is one having universal application in the determination of needed time magnification which plays such an important role in the photographic study of motion.

Events of Limited Duration

Some common events having finite duration are listed in Table II. This list also shows the necessary repetition rates and the corresponding time magnifications to cause each event to have the same duration on the projection screen. A time magnification of unity is assumed for the first event, and a projection rate of 24 frames per second for all events. A total of 2,400 frames would be required in each case to provide a duration of 10^2 sec on projection. High-speed photographs have been obtained of all these events, except possibly the electric spark in air. For the faster events, however, the repetition rates shown in the table have not been attained, nor has the 2,400-frame sequence.

Types of Photographic Records

Techniques for exposing photographs can be divided into two basic classes: *Image-forming* photography relates to the reproduction of a visual scene in two dimensions, whereas *non-image-forming* photography is a uni-dimensional representation of a variable, such as a recording of the electron beam on an oscilloscope screen. As in this case, time often appears as a second dimension in the photographic record. In non-image-forming photography, a focused point of light may move while the film remains stationary, the film only may move, or both the focused point and the film may move.

Under each of the two basic classifications, photographic techniques can involve *stills* or single frames, and *motion pictures* or multiple frames. Under each of the four classifications — image-forming stills and motion pictures, and non-image-forming stills and motion pictures—a further classification can be made as to *single exposure per frame* or *multiple exposures per frame*. However, multiple exposures per frame are only rarely produced in motion pictures.

Each classification can be further broken down on the basis of exposure duration per frame, and repetition rate or frames per second. For both stills and motion pictures, exposures per frame from 10^{-1} to 10^{-9} second have been reported.

Table II—Repetition Rates for Common Events of Limited Duration

EVENT	Duration of event, sec	Repetition rate needed, frames per sec	Time magnification when projected at 24 frames per sec
Complete history of major blasting operation	10^2	2.4 x 10	1
Formation of a spray plume from under water explosion	10	2.4 x 10^2	10
Persistence of incandescence of tungsten lamp	1	2.4 x 10^3	10^2
Burning of photoflash bulb filled with aluminum foil	10^{-1}	2.4 x 10^4	10^3
Single rotation of flywheel at 6,000 rpm	10^{-2}	2.4 x 10^5	10^4
Operation of fast camera shutter	10^{-3}	2.4 x 10^6	10^5
Detonation of an explosive charge	10^{-4}	2.4 x 10^7	10^6
Flash of xenon-filled tube	10^{-5}	2.4 x 10^8	10^7
Electric spark in air	10^{-6}	2.4 x 10^9	10^8

High-Speed Motion Pictures

The principal broad types of equipment for exposing motion pictures include intermittent, continuously moving film, drum, spark, electronic shutter and focal-plane scanning cameras. These cover a range of repetition rates up to 10^9 frames per second.

As the repetition rate increases, various difficulties and disadvantages are encountered. The apparatus becomes more complex and expensive. Resolution may be diminished. The maximum number of frames that can be exposed decreases. The maximum duration of the event that can be covered is reduced. Projectability may be impaired. The camera designer must strive to avoid all these disadvantages, and others, to the maximum extent possible. The degree of excellence of the compromise, between these qualities and the repetition rate, largely measures the value of any high-speed photographic equipment. The value of such equipment cannot be measured in terms of attainable repetition rate alone.

Repetition Rate and Duration of Exposure per Frame

The design engineer who wishes to utilize high-speed photography will be concerned at the outset with two equally important parameters: *Repetition rate* and *duration of exposure per frame*. When exposure durations per frame are adjustable independently of repetition rate, the repetition rate is governed principally by the degree of time magnification required, as discussed qualitatively above in the treatment of Events of Extended Duration. In many camera designs, however, the exposure duration is permanently fixed at some value inversely proportional to the repetition rate. When such cameras are used, the necessary repetition rate may be governed by the need for an exposure duration per frame not to exceed some definite value. This condition may result in an undesirably high repetition rate from the stand-

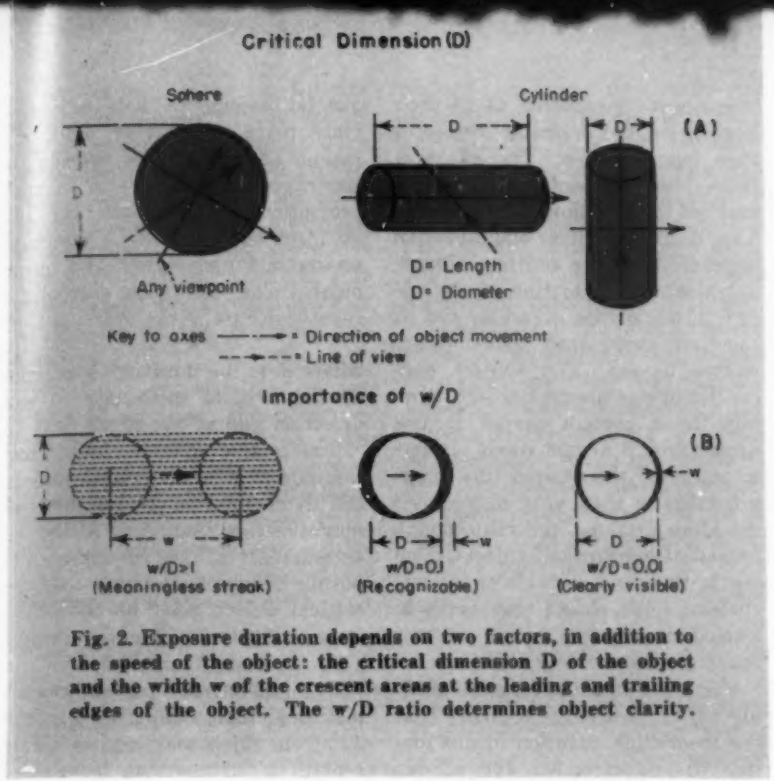


Fig. 2. Exposure duration depends on two factors, in addition to the speed of the object: the critical dimension D of the object and the width w of the crescent areas at the leading and trailing edges of the object. The w/D ratio determines object clarity.

point of the time magnification.

The practical upper limit for exposure duration is the reciprocal of the repetition rate. This value is not achieved in most designs because a large exposure duration is desirable only when the primary objective is a moving picture on the projection screen for study in slow motion. Often the primary objective is a series of still frames from which measurements can be made. In such cases, the most desirable exposure duration is the shortest compatible with adequate density.

If the dimensions of a moving object are given, the exposure duration determines the maximum translational velocity at which the object can be photographed. If the velocity of an object is stated, the exposure duration then determines the minimum dimensions of the object that can be photographed. The smaller the dimensions of a moving object or the greater its speed, the shorter must be the exposure.

When photographs are obtained primarily for projection on a screen as a motion picture, a median fineness of detail is acceptable. The resolution of the motion picture appears perceptibly better than the resolution of any particular frame. On the other hand, if accurate measurements are to be made from the individual frames as stills, a considerably finer resolution is needed. In such work, movement during the exposure of a frame must be minimized for any object whose position is to be measured.

In calculating the necessary exposure duration, the dimension of the moving object in the direction of motion, Fig. 2, is as important as the speed of the object. For a moving sphere, this dimension is the diameter. For a cylinder moving in the direction of its axis, the critical dimension is the length. If a cylinder were moving in a direction perpendicular to its axis, the diameter would be important. In any case, the critical dimension in inches of a moving object will be designated as D in the following discussions.

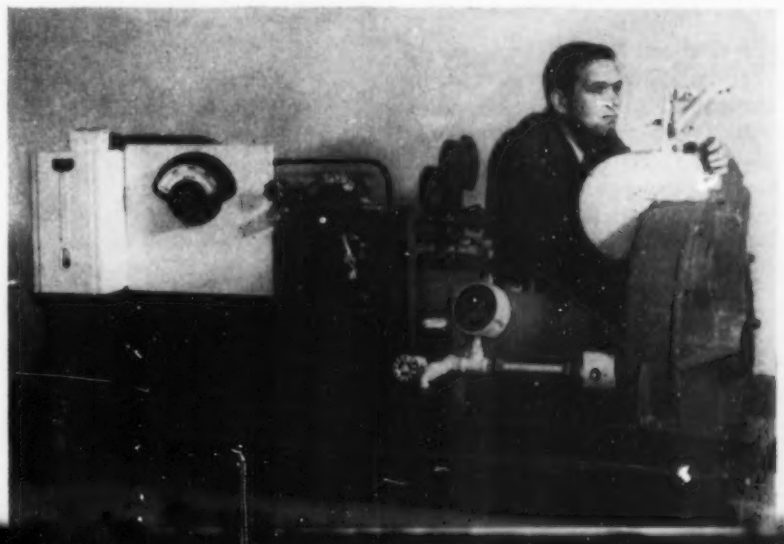
With finite exposure duration, the leading and trailing edges of any moving object will appear in the photographs not as sharp lines, but as shaded areas. The width of these areas, in the direction of motion, is equal to the distance through which the object moves during exposure (slightly less if the photographic emulsion requires an appreciable in inches will be designated w, as threshold exposure). This width measured on the subject rather than on the image.

In determining what the exposure duration must be, the design engineer must first decide how great a value of w can be tolerated. This decision may be controlled by one or the other of two factors. First, the ratio w/D must be small enough so that the object can be seen in the photographs. Second, w must not be of a larger order than the permissible error in measurement of the position of the object on the still frames.

If w/D is greater than unity, the object will not be visible in a still frame, except possibly as a meaningless streak. If w/D is about 0.1, the object will probably be recognizable, but its edges will be disconcertingly blurred. In most cases, a value of w/D of 0.01 is acceptable.

If w is two to four times as great as the permissible error in measure-

Fig. 3. Battelle camera, with author-designer Miller making an adjustment, is capable of 100,000 frames per sec. All photographs are taken through the same lens from same viewpoint, thus avoiding distortion from frame to frame. Camera can be used to photograph luminous or non-luminous objects, as well as for shadowgraph and schlieren studies. BATTELLE MEMORIAL INSTITUTE



ment of position, the center of the shaded area representing the leading or the trailing edge may possibly be estimated with sufficient accuracy. A value of w no greater than the permissible error is generally more satisfactory.

The tolerable value of w must be taken as the lower value determined on the basis of the acceptable value of w/D, or directly from the tolerable error in measurement of position. After this tolerable value of w has been determined, the maximum permissible exposure duration per frame, t, (in seconds) can be computed from the following equation, in which v represents the speed of the moving object in inches per second:

$$t = w/v \qquad (1)$$

In the Battelle high-speed camera, Fig. 3, and in one of the NACA-Miller cameras, a simple adjustment can be made to cause an object moving in a single direction at a constant speed to remain stationary on the film during exposure. This adjustment causes all stationary objects to move on the film in the opposite direction. However, it often happens that the moving object is small and the stationary objects are relatively much larger. In such cases, the motion of the larger objects on the film during exposure may not be objectionable. This adjustment permits much longer exposure durations than would result if Eq (1) is used.

When such a device cannot be applied to circumvent Eq (1), the required repetition rate may be governed by the value of t found from that equation. In most high-speed cameras, the repetition rate R (in frames per second) is related to t by the following equation, in which θ is a constant, characteristic of the camera,

$$R = \theta/t \qquad (2)$$

Often, the value of R dictated by Eq (2) is much higher than the value that would be determined from the desired time magnification. However, when this condition does not exist, the desirable time magnification can be used as the basis for choosing the repetition rate.

In the qualitative discussion above concerning Events of Extended Duration, three basic elements were considered as to their bearing on the desirable degree of time magnification. The effect of these basic elements can be summarized in the following statement: The desirable time magnification depends upon the *shortest* observable duration of motion of any object in a constant direction and at constant speed that the engineer wishes to see. The subject may consist of one discreet object, moving for a certain period in one direction and at one speed. Determination of the desired time magnification is then very simple. At the other extreme, the subject may consist of hundreds of objects, moving in various directions at various speeds. Each object may move in a constant direction and at constant speed for only a very brief period.

For the simpler case of one moving object, it is only necessary that the observable duration of the motion in one direction and at one speed be increased to a value that can be perceived by human consciousness. The *shortest* duration of such motion that can readily be perceived appears to be about one-quarter second. A half second is much more satisfactory, while durations of two or three seconds are superfluous. Thus, with normal projection at 24 frames per sec, six frames represent a practical minimum for resolution of a movement. The minimum acceptable repetition rate is therefore

$$R = 6/T, \qquad (3)$$

where T is the duration in seconds of the critical movement in one direction and at one speed.

The complex case of many moving objects is no more perplexing in the determination of needed time magnification than it is in the determination of the necessary exposure duration. In either case, the critical object must be chosen, in its most critical movement, and Eqs (1), (2) and (3) applied.

For satisfactory projection as a motion picture, small dimensions of a moving object may require higher repetition rates than would be needed on the basis of desired time magnification. If such an object moves through a distance greater than the critical dimension D, between the exposures of two suc-

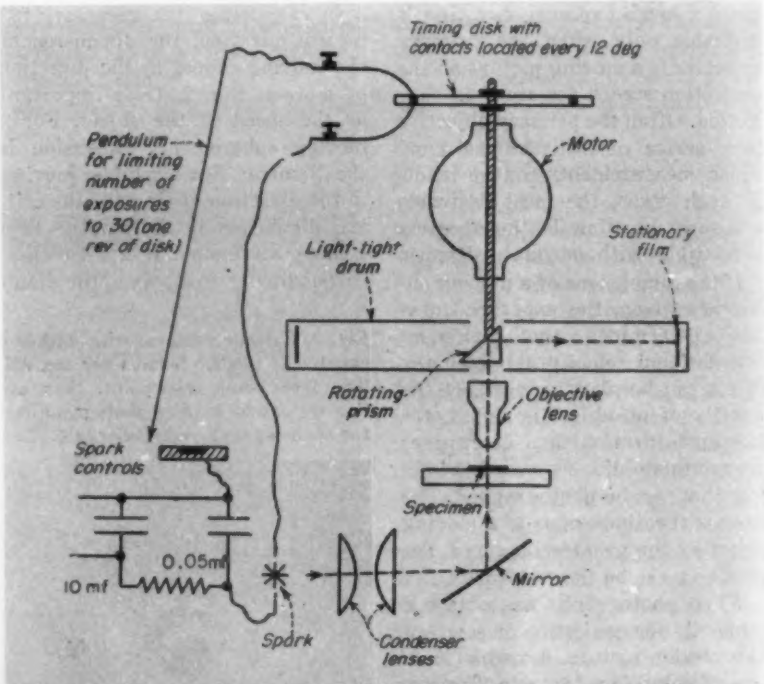


Fig. 4. High-speed cinephotomicrography is used when the subject under study has very small dimensions. Exposures as short as 0.1 microsec can be obtained by the method shown. Motor synchronizes rotation of prism and spark timing. Light from spark is transmitted through specimen and reflected by prism onto film in drum.

PRINCETON UNIVERSITY (HARVEY)

cessive frames, its motion will not be followed readily by the eye on the projection screen, even though the apparent duration of the movement is adequate. Thus, for satisfactory projection, the movement of the object between successive frames must be less than D. This criterion calls for a repetition rate conforming to the following inequality:

$$R > v/D \qquad (4)$$

In studies where the necessary data for determining R or t are not available, high-speed photography must be used qualitatively. Photographs taken at progressively higher rates are studied as motion pictures until the nature of the movements becomes clear.

Image Dimensions

One of the disadvantages that usually go with high repetition rates is small image size. In the design of a camera, it is general practice to choose the image size before the unit is built. Only a few cameras permit a change in the compromise between image size and repetition rate after assembly. In all cameras, the image size can be made as small as desired, but usually without a consequent increase in repetition rate.

In the design of a camera having a fixed ratio of repetition rate to exposure duration per frame, sacrifice of image size contributes toward both short exposure durations and high repetition rates. Although short exposure durations enhance the resolution of moving objects, small image size is directly detrimental to the resolution of both moving and still objects. Hence, as image size and exposure duration are progressively reduced, a point is reached at which the direct detrimental effect of reduction of image size offsets the advantage of the reduction of exposure duration.

A rough correlation exists between needed exposure duration and the ratio of image-to-object dimensions. In general, shorter exposure durations are required with cinephotomicrography than with small ratios of image-to-object dimensions. Such a rough correlation exists only because photomicrography involves smaller objects than normal photography. With the smaller moving objects, an acceptable value of w/D calls for lower values of w, and the permissible errors in measurement of position are usually smaller. This condition also dictates smaller values of w. Fig. 4 shows one setup for taking high-speed cinemicrophotographs.

Regardless of the ratio of image-to-object dimensions, the needed exposure duration for stopping movement is determined by Eq (1). When a phenomenon has been specified for study, and a decision made as to the tolerable blurring caused by motion of the object, the needed exposure duration is independent of the image dimensions.

Stroboscopic Photography

Concerned chiefly with high-speed stills, stroboscopic photography is useful in the study of repetitive phenomena, provided they are reproducible with sufficient accuracy from cycle to cycle. The successive high-speed stills are, of course, exposed at progressively later intervals in successive cycles of the phenomenon. It is even possible to skip one or more cycles between successive frames, provided only that each exposure is made at a later interval in a given cycle than was the preceding exposure in an earlier cycle. Such stroboscopic photography facilitates the use of repetition rates many orders lower than would be required if all exposures were to be made during a single cycle of the repetitive phenomenon. In this manner, the complexity and cost of the equipment can be greatly reduced, without changing the exposure duration.

Photographic Quality

Uniformity of exposure densities for different parts of the photographic image and the resolution for stationary objects, are dependent upon the choice of the optical system and the quality of its manufacture. Tonal values depend upon the freedom of the optical system from aberrations, and the care taken in processing the film. In general, the higher the repetition rate, the more difficult is the production of images of good quality. The final result represents compromises that affect image quality.

SAMPLE CALCULATIONS

A problem well suited to the application of high-speed photography is the determination of velocities and accelerations of type bars in a typewriter. Taking the approximate dimension of such a bar in the direction of motion as ¼ in. and the maximum velocity as 200 in. per sec, it is desired to determine bar speeds at maximum intervals of 0.5 in. to an accuracy of one percent.

A value for w/d of 0.1 results when w is 0.025 in. The requirement of speed determination within one percent, however, calls for w equal to 0.01 in. This value of w allows for half of the permissible one-percent error at each end of the assumed 0.5 in. travel, and results in a blurring of four times the permissible error. Using the smaller value of w in Eq (1), the exposure duration becomes

$$t = \frac{0.01}{200} = 5 \times 10^{-5} \text{ second.}$$

For the 16-mm Kodak high-speed camera, the ratio of exposure duration to the reciprocal of the repetition rate is approximately θ equal to 0.2. Applying Eq (2), the repetition rate is

$$R = 0.2/(5 \times 10^{-5}) = 4{,}000 \text{ frames per sec.}$$

As the camera is designed for operation at 3,000 frames per sec, the one-percent accuracy in determining bar speed can almost, but not quite, be achieved.

The repetition rate of 4,000 frames per sec will produce a frame for every 0.05-in. movement of the type bar as it moves at 200 in. per sec. Here is a case in which the requirement of short exposure time dictates a repetition rate 10 times as great as would otherwise be required.

In this example, the extreme accuracy within which measurements can be made on the photographic film, because of film grain and optical imperfections, is approximately 0.001 in. Again allowing half of the one-percent permissible error at each end of the specified 0.5 in. travel of the type bar, this limitation requires that the travel cover not less than $0.001 \times 2 \times 1/0.01 = 0.2$ in. on the film. The width of the 16 mm frame being 0.410 in., only a little more than an inch of travel of the type bar can be covered on the frame if the specified accuracy of speed determination is to be achieved from measurements of the photographs.

The relation of subject dimensions to image dimensions is governed by the equation:

$$w_s/w_i = p/q$$

where w_s is any given dimension in the subject, w_i is the corresponding dimension in the image, p is the subject-to-lens distance, and q is the image-to-lens distance. If a subject-to-lens distance of 18 in. is assumed, the image-to-lens distance for the typewriter bar would be

$$q = 18 \times 0.2/0.5 = 7.2 \text{ in.}$$

The focal length f of the lens would then need to be

$$f = \frac{18 \times 7.2}{18 + 7.2} = 5.14 \text{ in.}$$

Event Synchronization

The shorter the observable duration of an event, and the briefer the total operating time of photographic equipment, the more difficult is the synchronization of the camera with the event. All photographic equipment must incorporate means either to start photographing after sensing the inception of the event, or to initiate the event when the desired operational speed of the equipment has been reached.

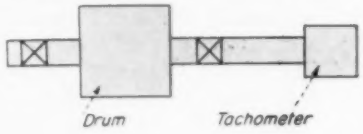
Establishment of Time Scale

Whether a study is quantitative or qualitative, a time scale is usually included in the photographic procedure. For the lower range of repetition rates, a light source controlled electronically or electrically records traces at known intervals on the edge of the film. This is necessary because cameras operating at these lower rates do not always run at constant speed throughout the exposure of the entire record. Such a time scale can be established with great accuracy, yet in a relatively simple manner. Table III lists types of time record that indicate either time interval between frames or frame frequency. It is often important to record elapsed time from a "zero" or to present the interval record as elapsed time.

At high repetition rates, the time scale is often established by noting the speed of a film drum or rotating optical element, such as a mirror, rather than by recording timing marks on the film. The time scale is not usually needed on photographs taken with high-rate equipment, because the cameras operate at constant speed throughout the exposure of all frames. Accuracies to 0.1 percent are general practice, and systems operated entirely by electronic means achieve still greater accuracies.

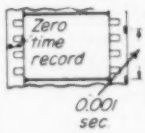
TABLE III—Typical Timing Systems

SEPARATE RECORD (not on film)

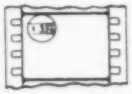


With drum and rotating-mirror cameras, various types of tachometers are generally used. This method of timing is best suited for applications involving relatively rapid events.

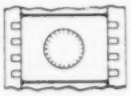
INTEGRAL RECORD (on film)



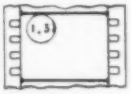
Time traces recorded on edge of film. Discharge lamp controlled by frequency standard.



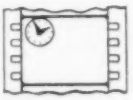
Mechanical or electro-mechanical counter or vernier device imaged on film.



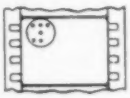
Calibrated disk or scale in field of view. This device is normally placed close to the plane of the subject.



Special cathode-ray tube system presenting time in form of arabic numerals.



Separate optical system that projects image of clock dial on film.



Binary or digital time code recorded in corner of film.

Photosensitive Materials

Photosensitive materials behave differently with short exposure durations than with ordinary exposure durations. The choice of a film for a high-speed photographic application depends upon its spectral characteristics and the spectral output of the light source under the short-duration conditions, the intensity of the source, the relative aperture of the optical system of the camera, the resolution of the film, the resolution of the optical system, and many other factors. With the lower repetition rates, for which adequate light sources are available, a choice can be made from a number of films; for high repetition rates, the choice of film must often be made on the basis of its photographic speed alone.

High-Speed Cameras

Of the many types known, the Eastman Kodak High-Speed Camera (Fig. 5), the Wollensak Optical Company's Fastax camera, the General Radio Company's Model 651-AG and the Warrick Model F continuously moving film cameras (used with multiple-flash light sources), are the most readily available commercially in this country. These cameras cover the speed range up to about 15,000 frames per second. Some of the larger industrial research laboratories, such as Battelle Memorial Institute, have cameras that can be operated at rates up to about 100,000 frames per second.

Principle of Operation

To accommodate the diverse needs of the engineering and research problems to which high-speed photography has been applied, many varieties of high-speed cameras have been developed. The process of invention and reinvention is continuing at an accelerated pace, and

it is not unusual for the same type of camera to be invented three to four times within a ten-year period. However, this great diversity of camera types is more or less justified because many problems require a camera that it tailor-made for the job. A systematic classification of known camera principles is therefore essential to engineers who deal with photographic problems. The gatefold at the end of this article shows this classification.

High-speed motion pictures are simply a series of high-speed stills exposed in rapid succession. Some of the photographic methods are capable of exposing only a very few frames in a series. Whether the results in such cases should be regarded as high-speed stills or as high-speed motion pictures is open to discussion. Thus, the applicability of the terms high-speed stills and high-speed motion pictures shades off gradually from one to the other.

The average amateur photographer would be sufficiently resourceful to find a solution if he wished to take two photographs of the same subject five seconds apart. He would focus two cameras on the subject, set up lights, and make other necessary preparations. With stopwatch in hand, he would then trip the shutter of one camera, and five seconds later, trip the shutter of the other camera.

If the amateur wished to expose the two photographs in much more rapid succession, or with more accurate timing, he might set up a simple mechanical device to trip the shutters more rapidly or with more exact timing than possible by hand. If he needed to expose three or more pictures in succession, instead of two, he might set up three or more cameras.

Basically, all techniques of exposing high-speed motion pictures involve this simple, logical procedure. All methods use multiple optical systems. Either an optical system is provided for each frame to be exposed, or a limited number of optical systems operate in rotation, the first being ready to operate again by the time the last has been used. The multiple optical systems usually contain some components in common. Occasionally, just as in the experiment by the hypothetical amateur, the photographic subject is the only common component. The frames on the photosensitive film constitute the only multiple component in multiple-flash motion pictures, but probably not in any other type of motion-picture photography above intermittent speeds.

Some device for switching from one optical system to the next is always used. This device often consists of relative motion between a common optical component and a multiple component. Likewise, all methods have a means of limiting the exposure duration for each optical system. The exposure duration can be limited by one of three methods: (1) Limiting the period for operation of the light source; (2) Moving the light beam out of coincidence with a component of the optical system, or moving the component out of coincidence with the light beam; (3) Interrupting the light beam with some type of shutter at a point between the light source and the photosensitive film.

Some optical parts may move during operation, or all parts may be stationary. If any parts move, consequent blurring of the photographic image on the film is held within tolerable limits by one of the following methods:

(1) The movements of two or more optical components, one of which may be the photosensitive film, are so related as to compensate each other. The photographic image consequently has little or no motion relative to the photosensitive film during exposure. This method is known as "optical compensation."

(2) The exposure duration is made several orders lower than the interval between frames. Photographs taken by this method are known as "multiple-flash motion pictures."

(3) A unit-dimensional photographic subject is used, with a uni-dimensional image, so that any finite movement of the image relative to the film automatically constitutes a new frame. Photographs taken by this method are referred to as "streak pictures."

Fig. 5 Commercially high speed cameras cover range from about 3,000 frames per sec for Eastman's Type III (below) to 15,000 frames per sec for Wollensak's Fastax (right).

EASTMAN KODAK COMPANY

WOLLENSAK OPTICAL COMPANY

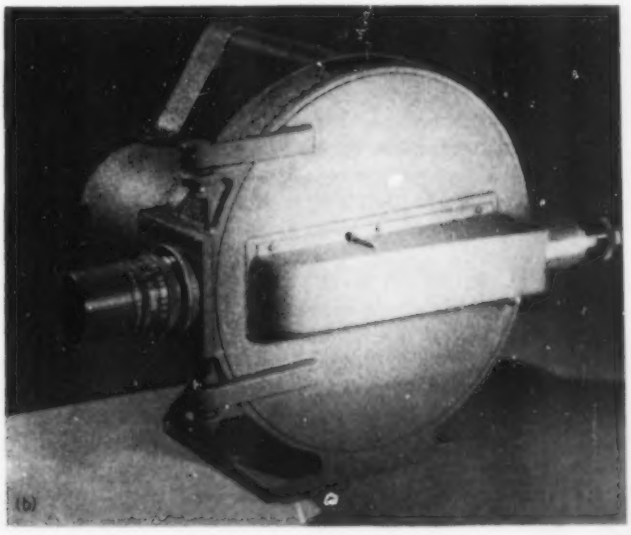


Table IV—Classification of Motion Picture Cameras

TYPE OF CAMERA	Rough designation of repetition rate	Range of repetition rates, frames per sec	Exposure duration per frame at max repetition rate, microsec		Order of magnitude of event that can be covered, sec.
			Max	Min	
Standard intermittent	Normal	Zero to 24	20,000	1,000	800
High-speed intermittent		24 to 275	1,800	36	75
Continuously moving film	High-speed	275 to 1.2×10^4	80	16	10^{-1}
Drum	Very high-speed	1.2×10^4 to 5×10^5	2	0.25	4×10^{-4}
Spark	Ultra-high-speed	5×10^5 to 10^8	1	0.10	2.4×10^{-6}
Electronic shutter		10^6 to 10^7	1	0.001	10^{-7}
Image dissection focal-plane scanning		10^7 to 10^9	0.001	0.001	3×10^{-9}

Variations in Camera Design

Several basic types of optically compensated cameras exist and they have been used separately or in combination. In addition to this classification of cameras on the basis of the optical systems used, there is also a grouping according to the type of film motion involved. Typical repetition rates, exposure durations, and total durations of events covered by each type camera are shown in Table IV above.

In the *intermittent* camera, the film frame is brought to rest during exposure, and the next frame advanced to the same position during the interval in which the camera shutter is closed between exposure of successive frames. The limitations of this type camera evolve from the strength of the film and the dynamics of a mechanical system involving high reciprocating speeds. The practical speed limit in the present state of development is about 275 frames per second, although somewhat higher-speed intermittent cameras have been designed. Optimum picture quality and accurate registration of frames are achieved within this speed range.

A camera involving *continuously moving film* has a supply reel and a take-up reel, just as does the intermittent type. Reel capacities are usually 100 ft, although some cameras do hold up to 1,000 feet. Film runs through the exposure gate at a constant or gradually accelerating speed throughout the exposure of a series. Either each successive image is moved with the film at constant speed by one of several mechanisms of optical compensation, or some type of shutter mechanism for control of the light source provides an exposure duration several orders lower than the interval between successive frames. For such control of the light source, electric sparks or gas-filled electric flash tubes can be used. Also practical for this purpose are the Kerr cell, the magneto-optic shutter and the electro-optic shutter, all of which involve the use of polarized light and the effect of transient electrostatic or magnetic fields on the birefringence (double refraction) of transparent liquids or solids.

The camera with continuously moving film extends into the next higher range of repetition rates than those achieved by the intermittent camera. The resolution is not as good as that of the intermittent and varies with the type of optical compensator. To a great extent, the resolution depends upon the degree of compromise the designer has accepted in attaining high repetition rates and simplicity of construction. The Eastman Kodak camera of this type is available for 16-mm film, and the Wollensak Fastax for 8-mm, 16-mm and 35-mm films. These cameras hold 100-ft lengths of film. Top speeds with 8-mm film are 12,000 to 15,000 frames per second. The General Radio and Warrick cameras permit maximum repetition rates of 1,500 and 2,000 frames per second and use the multiple-flash technique for image formation. Film capacity for the GR unit is 100 ft; for the Warrick, 1,000 feet.

For repetition rates in the range just above those attained with continuously moving film, *drum* cameras are used. Film is removed from the supply reel at the time of loading the camera and positioned on the inside or outside of a cylindrical drum, a spherical surface or some such geometrical area. During operation, either the drum rotates at high speed, or the drum and film remain stationary and optical means are provided to project stationary images onto different parts of the film in rapid succession. The necessity for advance loading of the film in position for exposing frames limits the length of series to a maximum of about a thousand frames.

The design of a drum camera is a complex engineering problem, because centrifugal stress, balance, windage and many other elements have to be controlled. Some of these cameras have high-speed rotating parts nearly six feet in diameter and weigh more than four tons. In the NACA-Miller II cameras, the film is stationary and a mirror wheel weighing two-thirds of a pound, with electromagnetic suspension and drive in a vacuum is driven at rates in excess of 2,500 revolutions per second. Repetition rates greater than 500,000 frames per second have been attained with this design.

Spark cameras and *electronic shutter* techniques reach into the

speed ranges just above those attainable with drum cameras. These arrangements involve the plan followed by the hypothetical amateur mentioned above, of setting up a complete camera or optical system for each frame to be exposed. The oldest of these arrangements is the mulitiple-spark system of Cranz and Schardin shown in the chart at the end of this article. More recently, the magneto-optic (Faraday) and electro-optic (Kerr and Pockels) effects have been used as shutters to control the operation of the individual optical systems. Image converter tubes have most recently been used for repetition rates of 10^7 frames per second and exposure durations as short as 10^{-8} second. These electronic techniques are complex and sometimes expensive, and the length of series is limited to a very few frames.

Image dissection and *focal-plane scanning* are closely related techniques, in which the field of view is subdivided into a number of parallel uni-dimensional images, comprising a television-type image. In one form, developed by Tuttle, an opaque screen ruled with fine transparent lines is placed almost in contact with the photographic emulsion. As the grid is moved in a direction perpendicular to the rulings, a streak photograph is produced through each ruling. The total time is limited to the interval during which one ruling moves to the position originally held by the next adjacent ruling. If the operating time is extended beyond this interval, double or triple exposures will occur, which, for some purposes, are useful. When the composite streak pictures are developed, and viewed through the same grid that was used in their exposure, a television-type frame is seen.

Sultanoff has placed the ruled screen at the focal plane of a primary image and has refocused across a rotating mirror onto a stationary photographic plate. Greater effective translation velocities of the focal-plane grid are thereby achieved. This camera has produced 10^8 frames per sec in a relatively long series.

In a system developed by O'Brien and Milne, the uni-dimensional images are laid out end to end on the film by a complex system of lenses and mirrors. Film is moved in a direction perpendicular to the one dimension of the images by a high-speed drum. This arrangement produces a long streak picture for each image, which must be reassembled for viewing.

The first camera of this type involved eight lines. Without change in the width of the film, increasing the number of lines to sixteen requires halving of the length of each line. With the small number of lines, resolution is good in the direction of the lines, but is bad in the perpendicular direction. As the number of lines is increased, the resolution becomes better in the perpendicular direction, but worse in the direction of the lines, because of the necessary reduction of the line length and the consequent increasing effect of film grain and optical imperfection. Good resolution in both directions is thus enmeshed in a three-way contradiction with reasonable film width. A satisfactory compromise among these three contradictory objectives has not been attained. However, this type camera has produced ultrahigh repetition rates of 2.2 x 10^7 frames per second, in a reasonably long series, and thus can be used for special purposes.

Typical High-Speed Photographic Studies

KNOCK IN PISTON ENGINE

The needs of this NACA study on fuel knock prompted the invention and development of two new types of high-speed camera. Referred to as the NACA-Miller I and II cameras, the first uses refocusing with translational movement of 90-deg reflector pairs in the focal plane of the primary image, while the second utilizes refocused revolving beams with a rotating mirror at the focal plane of the primary image.

Fuel knock imposes a severe limitation upon the performance of a spark-ignited piston engine, or upon the quality of the fuel used. In an attempt to learn the true

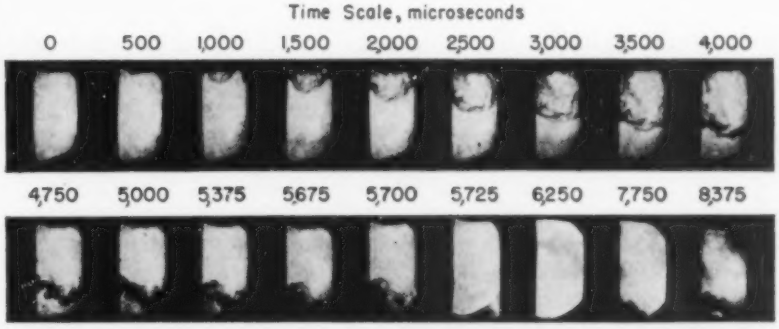


Fig. 6. Selected frames taken at 40,000 per sec of combustion and knock in a spark-ignited piston engine. Flame travels downward two-thirds of the way across the field of view in 4,000 microseconds. During the next 1,675 microsec, the "end-gas," not yet reached by the flame, undergoes the early stages of autoignition. Knock develops in the interval between 5,675 and 5,725 on the microsecond time scale. A black cloud of carbon smoke appears in the lower part of each frame at about 7,750 microsec and persists to the end of the series. Analysis of the photographs indicates that a 6,500 ft/sec detonation wave developed after about 5,725 microseconds.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

nature of knock, rates of motion were not of primary interest.

As in most cases where the test objective is to "see what happens," actual motion pictures were desired for observation on the screen, rather than a rapid sequence of high-speed stills from which measurements could be made. All that was known about the speed of knock propogation was that photographs previously taken with cameras commercially available were too slow. Repetition rates were therefore increased stepwise until the nature of knock was revealed.

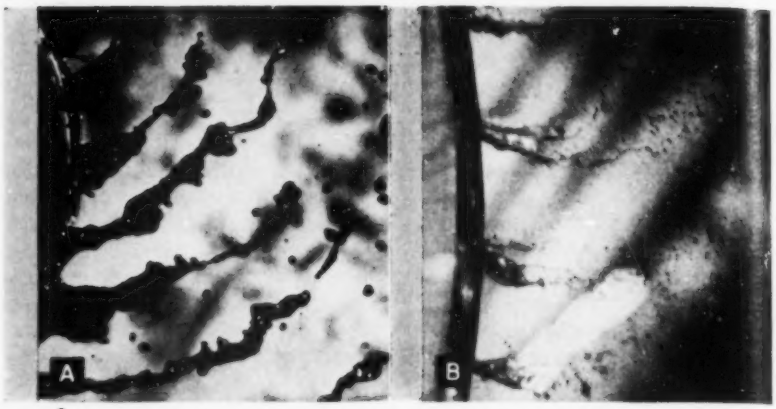


Fig. 7. Two-microsecond exposures showing atomization of water containing nigrosine dye. (A) shows atomization with a 7-in disk (18 curved vanes) rotating at 470 rpm, while (B) pictures a 3 3/4-in. disk (24 vanes) running at 7,600 rev per minute.

UNIVERSITY OF WISCONSIN

ATOMIZATION FOR SPRAY DRYING

Spray drying of solutions or suspensions of solid material in liquids has been the subject of study at the University of Wisconsin. Fine atomization is produced by flinging liquid as small-diameter droplets from high-speed rotating disks, Fig. 7. Very short exposure durations were essential.

Ordinarily, the performance of various disks turning at different speeds, and with diverse rates and methods of introducing the liquid to the surfaces, could be observed only on the basis of the end result. With high-speed photography, the trend toward better or worse atomization resulting from a change of any variable could be observed directly and accurately.

CAMERA: Speed Graphic

LIGHT SOURCE: General Electric xenon-filled flash tube

REPETITION RATE: High-speed stills

EXPOSURE DURATION: Two microseconds

EVENT SYNCHRONIZATION: By hand (not critical)

EMULSION: Superpan press and Super XX

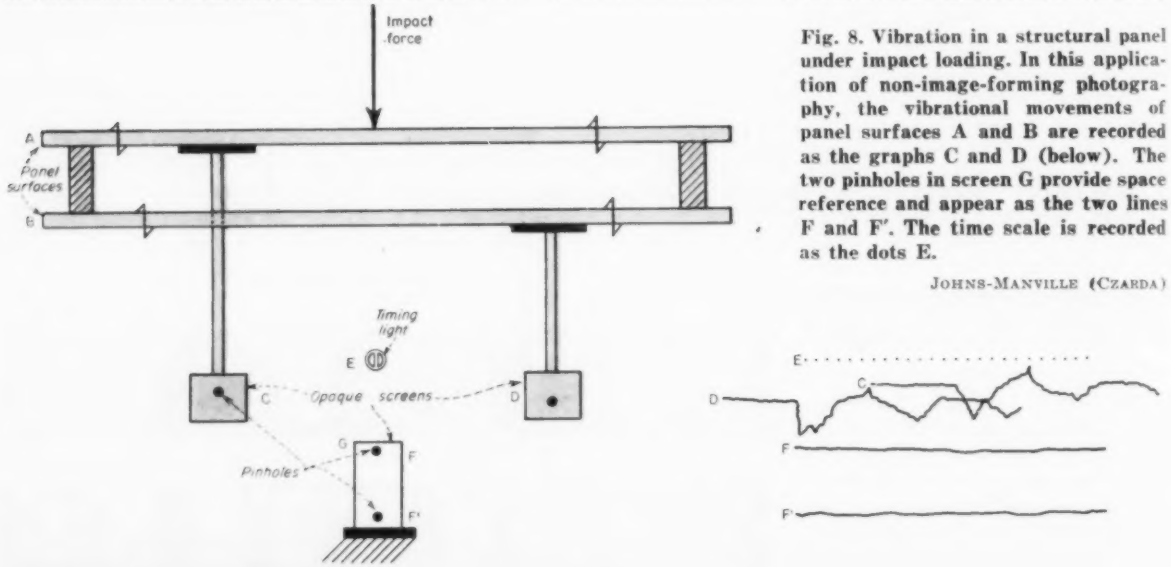


Fig. 8. Vibration in a structural panel under impact loading. In this application of non-image-forming photography, the vibrational movements of panel surfaces A and B are recorded as the graphs C and D (below). The two pinholes in screen G provide space reference and appear as the two lines F and F'. The time scale is recorded as the dots E.

JOHNS-MANVILLE (CZARDA)

VIBRATION IN STRUCTURAL PANEL

An application of non-image-forming photography at the Johns-Manville Research Center involves recording the entire history of vibration in a double structural panel upon impact loading. Fig. 8. shows schematically the photographic setup for recording vibrations and a composite graph of the two displacement-time curves.

An impact force is applied to surface *A*, which is connected to surface *B* by studding. Opaque screens *C* and *D*, attached to surfaces *A* and *B*, transmit light to an objective lens through single pinholes; and stationary screen *F*, transmits light through two pinholes located exactly one inch apart. Argon light, *E*, supplies 120 timing flashes per sec, which appear on the film as it moves through the focal plane in a direction perpendicular to the displacement of the panel surfaces.

This photographic method is a

relatively simple means for obtaining information in the study of shock and vibration phenomena. Analysis of the film (insert Fig. 8) reveals quantitative data such as amplitude and frequency of vibrations. See Product Engineering, July, 1949, for an analysis of shock in military vehicles.

FLUID FLOW THROUGH CENTRIFUGAL IMPELLER

Photographic records of tracer particles, Fig. 9, injected into the fluid entering transparent lucite impellers have furnished data for determining the velocity, flow path, and turbulence of the fluid, and for checking performance with design theory. Engineers at California Institute of Technology find such photographic data also gives an indication of the accuracy and limitations of other instruments.

An Eastman high-speed camera was used in this study, which incorporates a rotating prism to compensate for the translational movement of the film through the exposure gate. Additional optical compensation was used to handle rotation of the image on the film caused by the impeller rotation.

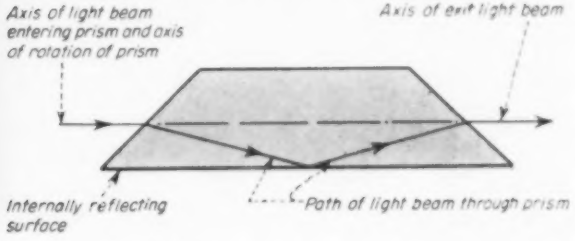
Any optical device rotating as a unit with angular velocity ω will impart an apparent angular velocity of 2ω to a stationary subject, provided the following conditions are satisfied: (1) The axis of the light beam leaving the rotating optical unit is identical with the rotational axis of the unit, and is an extension of the axis of the beam entering the unit from the stationary subject; and (2) the light beam undergoes an odd number of reflections from plane reflecting surfaces within the optical unit.

If such an optical unit is rotated at half the angular velocity of a subject rotating about the same axis, and in the *same* rotational sense, the rotating subject will appear to be stationary as viewed through the unit.

The optical element used for the rotational compensation is the well-known "dove" prism, Fig. 10. This prism has the disadvantage that nonparallel rays of light do not follow paths of equal length through the prism. Under the conditions of this study, the consequent aberrations in the image were slight.

A somewhat similar device has been used in a special optical printer in the laboratories of the National Advisory Committee for Aeronautics, but utilizing three front-surface mirrors and providing an optical path entirely free of glass. Such an arrangement avoids aberrations caused by unequal lengths of paths of nonparallel rays.

Fig. 9. The study of cavitation bubbles in fluid passing through a high-speed impeller required a repetition rate of about 1,000 frames per second. Frame shown was taken with an Eastman high-speed camera through "dove" prism (Fig 10, below) and rotated at half impeller speed. Only motions of the bubbles relative to the impeller are seen when the photographs are projected as a motion picture.
CALIFORNIA INSTITUTE OF TECHNOLOGY (KNAPP & PETERSON)


Axis of light beam entering prism and axis of rotation of prism
Axis of exit light beam
Internally reflecting surface
Path of light beam through prism

WAVE HEIGHT DETERMINATION IN TOWING BASIN

Although many of the characteristics of ship model performance, such as the forces, moments and accelerations related to wave heights and periods are recorded by galvanometric methods, valuable correlated information is obtainable from high-speed still photographs. Photographic records are produced by flashing two gaseous discharge tubes with the fixed camera's shutter open. The model is towed through a water channel by an overhead monorail carriage, Fig. 11, and a photoelectric cell used to trigger the camera and flash tubes when the carriage reaches a predetermined position. A mirror on the carriage provides the light impulse to energize the cell which, in turn, trips the camera shutter (set to 1/200 sec) and the flash-tubes.

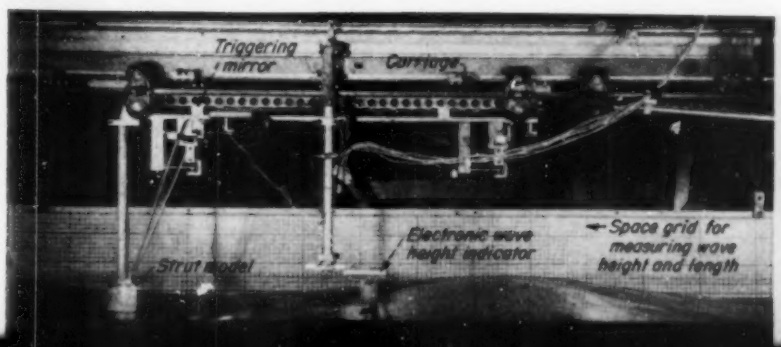


Fig. 11. High-speed still photography permits direct measurement of wave height and length at a given instant in an experimental towing tank. The waves shown are generated at the right and move to the left at about two fps. The carriage moves toward the right at speed of 15 ft per second.
STEVENS INSTITUTE OF TECHNOLOGY (SUTHERLAND)

Triggering of the 0.0005-sec flash units is recorded on the galvanometric record which provides time correlation with the rest of the data. A grid on the rear tank wall serves as a space reference for measurement of wave height and period. (Such grids often are used for reference in problems involving varying motion when velocities or accelerations of masses must be determined. In some cases timing marks can be exposed on the film so that calculations can be made directly.)

IMPACT FRACTURE OF STEEL

To determine the manner in which steel fractures on impact, standard V-notch Charpy test specimens heat-treated and cold-worked to various degrees were broken at room temperature using a conventional testing machine with a special striking edge. The 16-mm Fastax high-speed camera was used at various frame frequencies with a 4-in. lens set at $f/4$ and a 1-in. extension tube. Illumination was furnished by two 750R tungsten incandescent lamps. Event synchronization was manual.

Fig. 12 (top) shows the generation of the impact fracture considered normal for a tough grade of steel. This sequence was taken at 5,180 frames per sec and a frame duration of 48 microsec. The same steel cold-worked exhibits a brittle fracture as shown in bottom view. These exposures were taken at 4,580 frames per sec at a frame duration of 54 microsec. It is noteworthy that the "brittle" crack is generated between the second and third frames, during a time interval of only 218 microsec. Higher frame frequencies are required if accurate data on speed of crack propagation are desired.

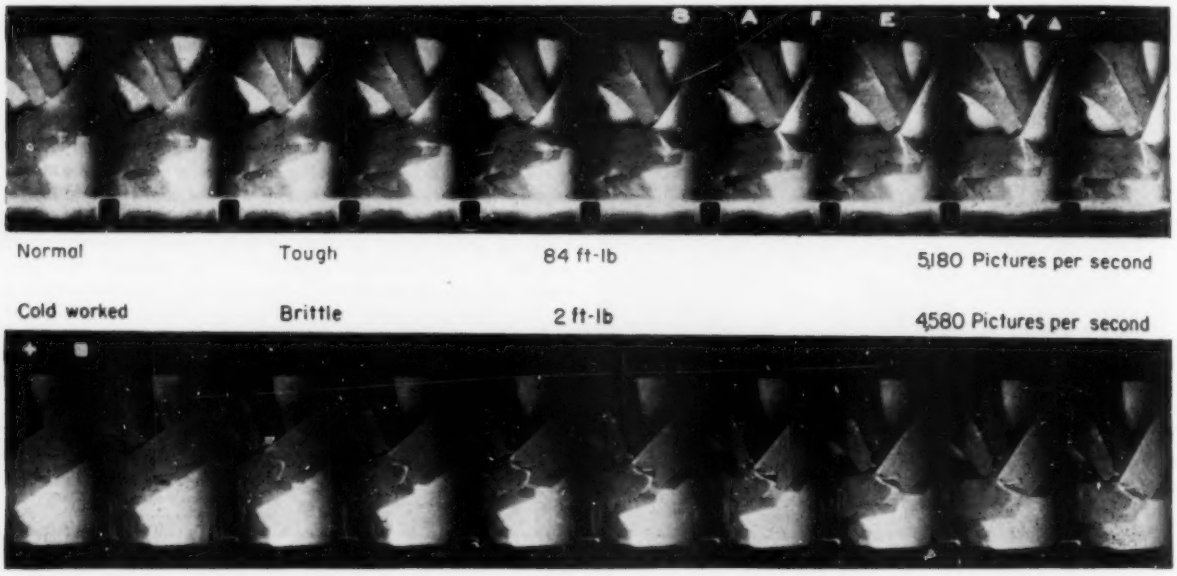


Fig. 12. Charpy impact fracture test of steel in "tough" condition (top) and "brittle" condition (bottom) is recorded on film. "Brittle" crack occurs between second and third frames. JONES & LAUGHLIN STEEL CORPORATION (STEWART)

CORRELATING MECHANICAL AND ELECTRICAL DATA

A problem sometimes encountered is correlation of mechanical movement with electrical characteristics. To simplify this problem, both the Eastman and Fastax high-speed cameras have been modified to record an oscilloscope trace simultaneously with the picture record. A second lens is set at 90 deg to the picture-taking lens so that the oscilloscope trace appears on the film record.

Film footage taken with the Eastman camera, Fig. 13, at 3,000 frames per sec or 900 in. per sec shows the oscilloscope trace of the electrical characteristics for relay contacts superimposed on the visual record of the phenomenon.

The original relay selected for an electronic control had been rejected because of contact bounce which was sufficiently pronounced to cause recycling of the device. An improved relay was tested and appeared to operate correctly as indicated in a conventional oscilloscope record taken at 6 in. per sec. However, since recycling was still occurring, the performance of the improved relay was checked with the Eastman camera to record both visual images and the oscilloscope trace. This record, Fig. 13 (A), shows repeated contact bounce, which was not evident in the conventional 6-in-per-sec oscilloscope record, Fig. 13 (B). Thus, time magnification is used to resolve this undesirable performance.

PROJECTILE PERFORMANCE AT GUN MUZZLE

Certain phenomena associated with ballistics are self-luminous and tend to obscure the projectile under study. A projectile emerging from a gun muzzle is surrounded by highly luminous gases which completely obscure it. These self-luminous effects are recorded on a photographic plate regardless of the shortness of the duration of the gaseous discharge or spark flash usually used to photograph such phenomena.

Studies made at the Canadian Armament Research and Development Establishment utilized an electronic shutter, or Kerr cell, operating in synchronization with a gaseous discharge tube flash source. A Kerr cell consists of a glass cell filled with nitrobenzene and carrying two or more electrodes. A polarizer and analyzer (a second polarizer set with its plane of polarization at 90 deg to that of the first polarizer) are placed on either side of the glass cell.

This system passes almost no light until electrical energization causes the nitrobenzene to rotate the polarization plane of the light so that it passes through the analyzer, thereby "opening" the cell shutter. Upon de-energization, cell shutter is "closed". The duration of the "opening" is electronically controlled and can be as short as 0.04×10^{-6} sec. Notable disadvantages of the Kerr cell are small angular opening and large light loss.

In the Canadian Armament Research setup, the manual camera shutter is opened and the discharge tube triggered. At peak flash intensity, the Kerr cell is energized at 36 kv for a period of about two microsec, thereby passing light to the film. The Kerr cell shutter is then de-energized and the manual camera shutter closed to exclude any light still transmitted through the cell's polarizers. Thus the exposure is made essentially with the flash illumination and the ambient light (self-luminous phenomena)

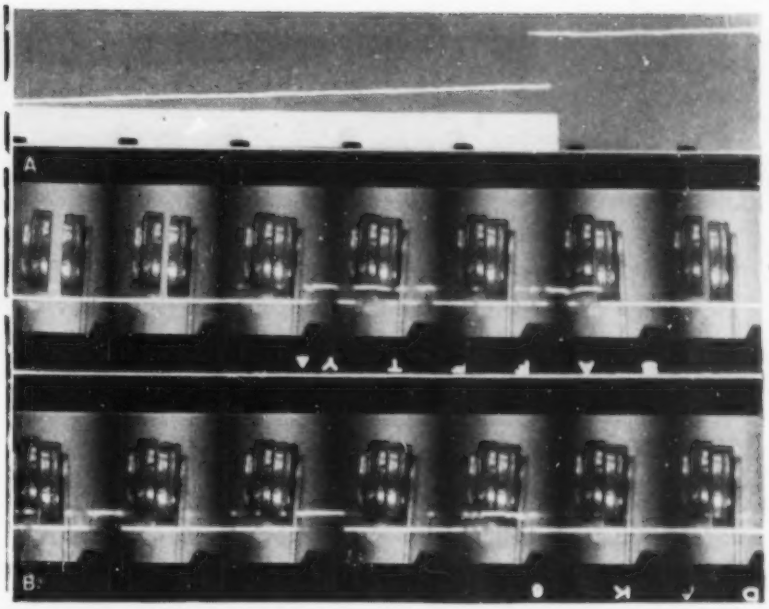


Fig. 13. Combined high-speed photography and oscillography of relay contact bounce. Superimposed oscilloscope trace (A) taken at 3,000 frames per second (900 in. per sec) shows intermittent bounce, while conventional oscilloscope record (B) taken at 6 in. per sec does not reveal the bounce.

EASTMAN KODAK COMPANY (QUINN)

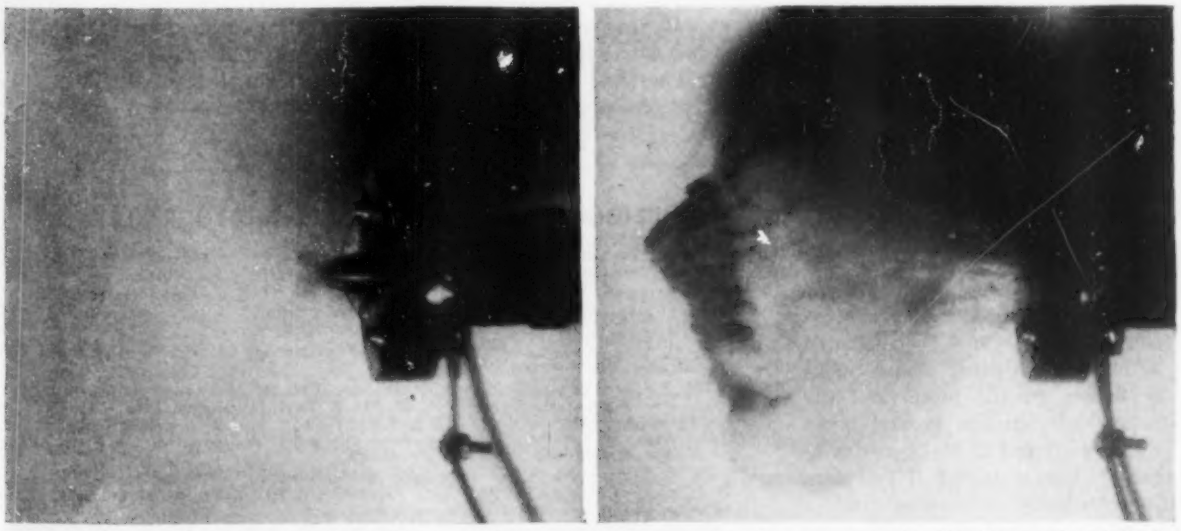


Fig. 14. Kerr cell photograph (left) shows a 20-mm projectile emerging from gun muzzle. The Kerr cell and flash are initiated by contact of the projectile with the wire strung about 0.5 in. outboard of the muzzle. (Right) is a study of the gas cloud surrounding the projectile.

CANADIAN ARMAMENT RESEARCH & DEVELOPMENT ESTABLISHMENT

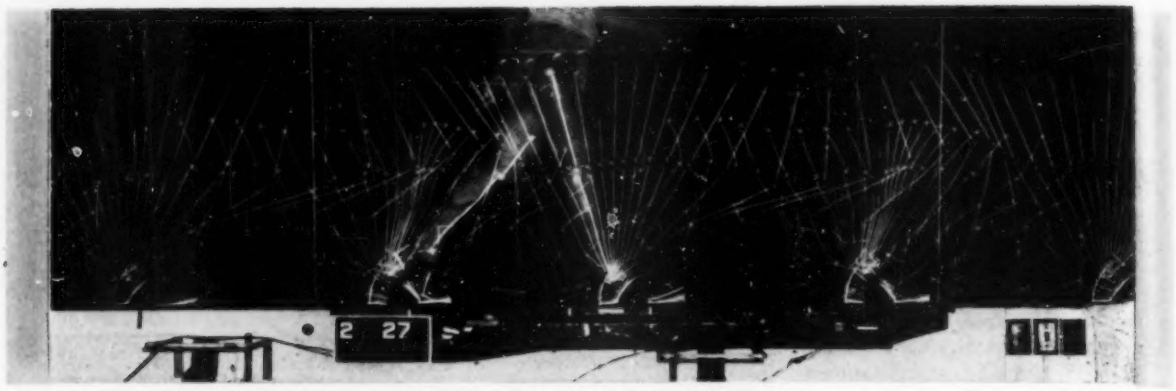


Fig. 15. "Stick" figures show successive positions of artificial leg as subject walks. An interrupted-light camera with rotating disk shutter and gaseous discharge tube trigger supplies data regarding velocities of joints and gait pattern. VETERANS' ADMINISTRATION

excluded by the Kerr cell. In this instance, event synchronization is of particular importance.

Figs. 14 (A) and (B) show Kerr cell high-speed photographs taken as a 20-mm projectile is fired. The projectile is clearly visible and the gas cloud pattern defined. Without the use of the special photographic technique, both projectile and cloud would be obscured by the latter's ambient illumination.

TECHNIQUES FOR TESTING ARTICULATED MEMBERS

In evaluating artificial limbs, the forces the foot exerts on the ground during level walking are measured, the instantaneous horizontal velocity of the subject's center of gravity is determined and a photographic record is made of the subject's gait.

To measure the forces the foot exerts on the ground, a pair of force plates recessed in a walkway are supported at their corners by aluminum columns. Fifty resistance strain gages placed on the columns are connected to six Wheatstone bridges that measure: vertical load, the *X* and *Y* position of the load, the turning couple about the center of the plate, and the shear forces in the ground plane in line with and at right angles to the direction of travel. These data are recorded on an oscillograph.

The equipment used to measure the instantaneous velocity of the subject's center of gravity consists of a loop of cord attached to a belt worn by the subject at his center of gravity. The moving cord drives a d-c generator, the output of which is amplified and recorded on one of the oscillograph channels. The amplitude of this signal is proportional to velocity.

To obtain a photographic record of a subject's visible gait characteristics, an interrupted-light camera is used. The subject's legs are marked with highly reflective "Scotch-lite" tape which directs light into the camera, and the subject is illuminated by a continuous light source which is interrupted periodically by a rotating, slotted disk shutter placed in front of the lens. Thus "stick" images are produced, Fig. 15, by the single plate multiple-exposure technique, which traces out graphs of the phenomenon upon connecting up the related points. The time interval between "stick" pictures is 0.05 sec because the slotted disk is rotating at 1,200 rpm and the disk slot angle is chosen to provide an exposure duration of about 1/500 second.

At the moment the subject reaches the center of his pass before the camera, a photoelectric relay is tripped by his body and fires a gaseous discharge tube, which is synchronized with the interrupter disk position by an auxiliary photocell. This cell is energized by a small electric lamp each time the disk slot passes the shutter; and through the use of suitable amplifying and wave-shaping circuits, it generates timing marks and trigger pulses. The timing marks indicating shutter opening are recorded on the oscillograph to permit correlation of the photographic "stick" pictures with the oscillograph traces of force information.

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Solution of the Cubic Equation By a Simplified Procedure

Time-saving and practical method for the solution of the cubic equation. Use of simplified method requires only a knowledge of elementary algebra and the ability to interpolate values from included tables. Procedure covers the determination of complex as well as real roots. Application of procedure is demonstrated by solutions of three typical equations. Basis of the method is summarized to enable reconstruction of the steps in the method.

ENNIS E. JONES
Research Engineer
Minneapolis-Honeywell Regulator Company

MECHANICAL, electrical and electronic analogies for the solution of engineering problems are rapidly gaining favor in the field of product design and development. The increasing use of these methods, to derive the relation between variables in complex systems, reflects a general acceptance of the proposition that the analytical approach to a problem in applied science is often more productive, costs less, and is less time consuming than the experimental approach.

Many engineers engaged in applied science, fortunately, have no difficulty with the mathematical reasoning required to set up design or performance equations. Lack of skill, however, in handling the complex computations often involved in solving such equations frequently discourages attempting the analytical approach. Also, if the engineer is not a mathematical specialist, such problems are likely to be time-consuming and irksome.

Some of the most common of the complex computations encountered are found in the solution of cubic equations. Methods such as Horner's, Newton's, Graeffe's, and Sohon's have one denominator in common: They require much practice for developing speed and accuracy in their use.

To overcome this drawback, the author has developed a simplified method of solving cubic equations. Application of the method requires little more background than high school algebra. The response from several departments of the author's company, where the method is used, indicates that it is a useful tool.

On distribution of the method throughout the company, it was discovered that the same method had been developed earlier and given a limited distribution in a mimeographed leaflet. This leaflet is entitled "Solution of Cubic and Quartic Equations;" its author is W. V. Lyon of the Electrical Engineering Department, Massachusetts Institute of Technology.

Except for differences in terminology, the basic methods of the two presentations are identical. The scope and arrangement, however, of the data supplied for application of the methods differ considerably.

Method of Solution

The solution involves four steps after the cubic equation has been reduced to the form

$$x^3 + ax^2 + bx + c = 0 \tag{1}$$

STEP 1. Using the coefficients in Eq (1) evaluate the quantity

$$b - (a^2/3) \tag{2}$$

which is the slope of the cubic curve at its point of inflection.

STEP 2. The sign of the result obtained in Step 1 determines one of three procedures:

Case I: (—). When the sign of the result from Step 1 is negative, calculate the value of a term designated as v from

$$v = \left(\frac{ab}{3} - \frac{2a^3}{27} - c\right) \Big/ \left(\frac{a^2}{3} - b\right)^{3/2} \tag{3A}$$

Case II: (0). When the result from Step I is zero, calculate the term v from

$$v = (a^2/27) - c \tag{3B}$$

Case III: (+). When the sign of the result from Step 1 is positive, calculate the term v from

$$v = \left(\frac{ab}{3} - \frac{2a^3}{27} - c\right) \Big/ \left(b - \frac{a^2}{3}\right)^{3/2} \tag{3C}$$

STEP 3. *For Case I:* When the calculated value of v from Eq (3A) is greater than 0.3849, obtain the values of u_1 and u_4 from the first portion of the accompanying Table II. When v from Eq (3A) is equal to or less than 0.3849, obtain values of u_1, u_2, and u_3 from the second portion of Table II.

Values of u terms take a negative sign when the sign of v is negative.

For Case II. Using the calculated value of v from Eq (3B), calculate

$$u_1 = \sqrt[3]{v} \tag{4A}$$

$$u_2 = (u_1/2)(-1 + j\sqrt{3}), \quad \text{where } j = \sqrt{-1} \tag{4B}$$

$$u_3 = (u_1/2)(-1 - j\sqrt{3}) \tag{4C}$$

For Case III. Using the calculated value of v from Eq (3C), obtain the values of u_1 and u_4 from Table III.

Values of u terms take a negative sign when the sign of v is negative.

STEP 4. *For Case I:* When the calculated value of v from Eq (3A) is greater than 0.3849, calculate the roots X_1, X_2, and X_3 of the cubic equation

$$X_1 = u_1\sqrt{(a^2/3) - b} - (a/3) \tag{5A}$$

$$X_2 = \left[-\frac{u_1}{2} + ju_4\right]\sqrt{(a^2/3) - b} - (a/3) \tag{5B}$$

$$X_3 = \left[-\frac{u_1}{2} - ju_4\right]\sqrt{(a^2/3) - b} - (a/3) \tag{5C}$$

When the calculated value of v from Eq (3A) is equal to or less than 0.3849, calculate the roots X_1, X_2, and X_3 of the cubic equation from

$$X_1 = u_1 \sqrt{(a^2/3) - b} - (a/3) \quad (5D)$$

$$X_2 = -u_2 \sqrt{(a^2/3) - b} - (a/3) \quad (5E)$$

$$X_3 = -u_3 \sqrt{(a^2/3) - b} - (a/3) \quad (5F)$$

For Case II. Using the values of u_1, u_2, and u_3 as calculated from Eqs (4A), (4B) and (4C) calculate the roots X_1, X_2, and X_3 of the cubic equation from

$$X_1 = u_1 - (a/3) \quad (6A)$$

$$X_2 = u_2 - (a/3) \quad (6B)$$

$$X_3 = u_3 - (a/3) \quad (6C)$$

For Case III. Calculate the roots X_1, X_2, and X_3 of the cubic equation from

$$X_1 = u_1 \sqrt{b - (a^2/3)} - (a/3) \quad (7A)$$

$$X_2 = \left(-\frac{u_1}{2} + ju_4\right)\sqrt{b - (a^2/3)} - (a/3) \quad (7B)$$

$$X_3 = \left(-\frac{u_1}{2} - ju_4\right)\sqrt{b - (a^2/3)} - (a/3) \quad (7C)$$

EXAMPLE 1: Find the roots of the cubic equation

$$x^3 - 5x^2 - 22x + 140 = 0$$

SOLUTION:

STEP 1. Evaluate the quantity

$$b - (a^2/3) = -22 - [(-5)^2/3] = -30.3333$$

The negative sign of this quantity identifies the cubic equation as Case I.

STEP 2. Evaluate Eq (3A)

$$v = \left(\frac{ab}{3} - \frac{2a^3}{27} - c\right) \Big/ \left(\frac{a^2}{3} - b\right)^{3/2}$$

$$= \left[\frac{(-5)(-22)}{3} - \frac{2(-5)^3}{27} - 140\right] \div \left[\frac{(-5)^2}{3} - (-22)\right]^{3/2}$$

$$= -0.564$$

STEP 3. Since v is greater than 0.3849, obtain values of u_1 and u_4 from Table II for v equal to 0.564, then reverse signs of u_1 and u_4 because v is negative.

$$u_1 = -1.2107$$

$$u_4 = -0.3146$$

STEP 4. Calculate the roots X_1, X_2, and X_3 from Eqs (5A), and (5B) and (5C).

$$X_1 = u_1 \sqrt{(a^2/3) - b} - (a/3)$$
$$= -1.2107 \sqrt{[(-5)^2/3] - (-22)} - (-5)/3$$
$$= -5.00$$

$$X_2 = \left[-\frac{u_1}{2} + ju_4\right]\sqrt{(a^2/3) - b} - (a/3)$$
$$= \left[-\frac{-1.2107}{2} + j(-0.3146)\right] \times \sqrt{[(-5)^2/3] - (-22)} - (-5)/3$$
$$= 5.00 - j\,1.732$$

$$X_3 = \left[-\frac{u_1}{2} - ju_4\right]\sqrt{(a^2/3) - b} - (a/3)$$
$$= \left[-\frac{-1.2107}{2} - j(-0.3146)\right] \times \sqrt{[(-5)^2/3] - (-22)} - (-5)/3$$
$$= 5.00 + j\,1.732$$

Since complex roots occur in conjugate pairs, X_3 could be written immediately by reversing the sign of the j term of X_2.

EXAMPLE 2. Find the roots of the cubic equation

$$x^3 - 3x^2 + 3x + 7 = 0$$

SOLUTION:

Step 1. Evaluate the quantity

$$b - (a^2/3) = 3 - [(-3)^2/3] = 3 - 3 = 0$$

Since the value of this quantity is zero, the cubic equation is identified as being in Case II.

Step 2. Evaluate Eq (3B)

$$v = (a^3/27) - c = [(-3)^3/27] - 7 = -8$$

Step 3. Evaluate Eqs (4A), (4B) and (4C)

$$u_1 = \sqrt[3]{v} = \sqrt[3]{-8} = -2$$

$$u_2 = (u_1/2)(-1 + j\sqrt{3})$$
$$= (-2/2)(-1 + j\sqrt{3}) = 1 - j\sqrt{3}$$

$$u_3 = (u_1/2)(-1 - j\sqrt{3})$$
$$= (-2/2)(-1 - j\sqrt{3}) = 1 + j\sqrt{3}$$

Again, u_3 could have been written immediately as the conjugate of u_2.

Step 4. Calculate the roots X_1, X_2, and X_3 of the cubic equation from Eqs (6A), (6B), and (6C).

$$X_1 = u_1 - (a/3)$$
$$= -2 - (-3/3) = -1$$

$$X_2 = u_2 - (a/3)$$
$$= (1 - j\sqrt{3}) - (-3/3) = 2 - j\sqrt{3}$$

$$X_3 = u_3 - (a/3)$$
$$= (1 + j\sqrt{3}) - (-3/3) = 2 + j\sqrt{3}$$

which is seen to be the conjugate of X_2.

EXAMPLE 3. Find the roots of the cubic equation

$$x^3 - 5x^2 + 14x - 24 = 0$$

SOLUTION:

Step 1. Evaluate the quantity

$$b - (a^2/3) = 14 - (-5^2/3) = 5.6667$$

The plus sign of this quantity identifies the cubic equation as Case III.

Step 2. Evaluate Eq (3C)

$$v = \left(\frac{ab}{3} - \frac{2a^3}{27} - c\right) \Big/ \left(b - \frac{a^2}{3}\right)^{3/2}$$

$$= \left[\frac{(-5)(14)}{3} - \frac{2(-5)^3}{27} + 24\right] \div \left[14 - \frac{(-5)^2}{3}\right]^{3/2}$$

$$= 0.73583$$

Step 3. Obtain values of u_1 and u_4 from Table III for v equal to 0.73583

$$u_1 = 0.5601$$

$$u_4 = 1.1114$$

Step 4. Calculate the roots X_1, X_2, and X_3 from Eqs (7A), (7B), and (7C).

$$X_1 = u_1 \sqrt{b - (a^2/3)} - (a/3)$$
$$= 0.5601 \sqrt{14 - (-5^2/3)} - (-5/3)$$
$$= 3$$

$$X_2 = \left(-\frac{u_1}{2} + ju_4\right)\sqrt{b - (a^2/3)} - (a/3)$$
$$= \left(-\frac{0.5601}{2} + j\,1.1114\right) \times \sqrt{14 - (-5^2/3)} - (-5/3)$$
$$= 1 + j\,2.6456$$

$$X_3 = \left(-\frac{u_1}{2} - ju_4\right)\sqrt{b - (a^2/3)} - (a/3)$$
$$= \left(-\frac{0.5601}{2} - j\,1.1114\right) \times \sqrt{14 - (-5^2/3)} - (-5/3)$$
$$= 1 - j\,2.6456$$

Since complex roots occur in conjugate pairs, X_3 could have been obtained immediately from X_2.

Calculation of Precise Values

The values of the u terms given in Tables II and III were computed from the following equations. These equations can be used to increase the degree of precision of the method beyond that attainable from use of Tables II and III.

Case I: For values of v greater than 0.3849, calculate values of u_1 and u_4 from

$$u_1 = \left[\frac{v}{2} + \sqrt{\left(\frac{v}{2}\right)^2 - \frac{1}{27}}\right]^{1/3} + \left[\frac{v}{2} - \sqrt{\left(\frac{v}{2}\right)^2 - \frac{1}{27}}\right]^{1/3} \quad (8A)$$

$$u_4 = \frac{1}{2}\sqrt{3u_1^2 - 4} \quad (8B)$$

For values of v equal to or less than 0.3849, calculate values of u_1, u_2, and u_3 from

$$u_1 = 2\sqrt{-\frac{1}{3}} \times \cos\left[\frac{\cos^{-1}[(v/2)\sqrt{27}]}{3}\right] \quad (8C)$$

$$u_2 = 2\sqrt{-\frac{1}{3}} \times \cos\left[120^\circ + \frac{\cos^{-1}[(v/2)\sqrt{27}]}{3}\right] \quad (8D)$$

$$u_3 = 2\sqrt{-\frac{1}{3}} \times \cos\left[120^\circ - \frac{\cos^{-1}[(v/2)\sqrt{27}]}{3}\right] \quad (8E)$$

Case III:

$$u_1 = \left[\frac{v}{2} + \sqrt{\left(\frac{v}{2}\right)^2 + \frac{1}{27}}\right]^{1/3} + \left[\frac{v}{2} - \sqrt{\left(\frac{v}{2}\right)^2 + \frac{1}{27}}\right]$$

$$u_4 = \frac{1}{2}\sqrt{4 + 3u_1^2} \quad (9B)$$

Calculation of Approximate Values

When the calculated value of v from Eq (3A) or (3C) is too large to be found in Tables II and III, close approximations for the value of the u terms can be calculated from:

Case I: For values of v greater than 210, approximate values of u_1 and u_4 are:

$$u_1 = \sqrt[3]{v} + (1/3)\,(1/\sqrt[3]{v})$$
$$u_4 = \sqrt{(3u_1^2)/4 - 1}$$

Case III: For values of v greater than 230, approximate values of u_1 and u_4 are:

$$u_1 = \sqrt[3]{v} - (1/3)\,(1/\sqrt[3]{v})$$
$$u_4 = \sqrt{1 + (3u_1^2)/4}$$

When the calculated value of v from Eq (3A) or (3C) is smaller than 0.100, approximations for value of the u terms can be calculated from:

Case I:

$$u_1 = 1 + \frac{v}{2} - \frac{3v^2}{8} + \frac{v^3}{2}$$

$$u_2 = -v - v^3$$

$$u_3 = -1 + \frac{v}{2} + \frac{3v^2}{8} + \frac{v^3}{2}$$

Case III:

$$u_1 = +(v - v^3)$$

$$u_4 = \frac{1}{2}\sqrt{4 + 3u_1^2}$$

Basis of the Method

For economy of space, the derivation of the method is not presented in this article. Interested readers, however, may reconstruct the steps in the method from the following summary.

1. With the cubic equation stated in the form of that of Eq (1), determine the coordinates of the point of inflection.

2. Restate the cubic equation in terms of new coordinates in reference to new axes that intersect at the point of inflection of the cubic curve.

Three distinct cases arise. Each is identified by the sign of the slope of the cubic curve at its point of inflection.

3. *Case I.* When the slope of the curve at the point of inflection is negative, an appropriate change of scale is made such that the abscissas u and the ordinates v referred to the new axes have the relation

$$v = u^3 - u$$

Case II. When the slope of the curve at the point of inflection is zero, the abscissas u and the ordinates v referred to the new axes have the relation

$$v = u^3$$

Case III. When the slope of the curve at the point of inflection is positive, an appropriate change of scale is made such that the abscissas u and the ordinates v when referred to the new axes have the following relation

$$v = u^3 + u$$

Since in all three cases to every value of x there corresponds a value of u, and to every value of y there corresponds a value of v, the three roots X_1, X_2, and X_3 of the original equation correspond to the three values of u for the value of v that corresponds to y equal to zero.

Hence, if v is determined for y equal to zero, then either on a graph of the transformed equation or in a table of calculated points of the transformed equation, there can be found three values of u for y equal to zero that yield the three roots X_1, X_2 and X_3 of the original equation. Moreover, the nature of u (whether real or complex) is the same as that of X. Consequently, if only real roots are desired, the complex values of u may be discarded.

The results of the foregoing procedure are given in Tables II and III. Access to an IBM calculator enabled the author to extend his procedure to provide for the determination of complex as well as real roots. With the calculator and using Eqs (8) and (9), the values in Tables II and III were computed for values of v at intervals that provide maximum facility of interpolation. The range of Tables II and III is broad enough to cover all cases in which tables yield greater accuracy than can be attained by approximation methods.

Table I—Relation Between Cubic Equation and Transformed Equation

Cubic equation has the form: $x^3 + ax^2 + bx + c = 0$

Case	Transformation	Transformed Equation	Sign of Slope at Inflection point	Curve
I	$x = u\sqrt{\frac{a^2}{3} - b} - \frac{a}{3}$ $y = v\left(\frac{a^2}{3} - b\right)^{3/2} + \left(\frac{2a^3}{27} - \frac{ab}{3} + c\right)$	$v = u^3 - u$	−	
II	$x = u - \frac{a}{3}$ $y = v + c - \left(\frac{a}{3}\right)^3$	$v = u^3$	0	
III	$x = u\sqrt{b - \frac{a^2}{3}} - \frac{a}{3}$ $y = v\left(b - \frac{a^2}{3}\right)^{3/2} + \left(\frac{2a^3}{27} - \frac{ab}{3} + c\right)$	$v = u^3 + u$	+	

Table II—Case I: Slope at Inflection Point is Negative

$b - (a^2/3)$ = a negative quantity

PORTION I

Values of u_3 and u_4 for v greater than 0.3849. When v is negative, values given for u_3 and u_4 take a negative sign.

p	u_3	u_4	p	u_3	u_4	p	u_3	u_4	p	u_3	u_4
210.0	6.0000	5.0990	64.0	4.0833	3.3919	15.000	2.6012	2.0186	3.400	1.7240	1.1087
205.0	5.9529	5.0574	62.0	4.0421	3.3547	14.500	2.5751	1.9933	3.300	1.7113	1.0938
200.0	5.9050	5.0152	60.0	4.0000	3.3166	14.000	2.5483	1.9673	3.200	1.6983	1.0785
195.0	5.8564	4.9722	58.0	3.9570	3.2777	13.500	2.5209	1.9407	3.100	1.6851	1.0629
190.0	5.8069	4.9285	56.0	3.9130	3.2378	13.000	2.4929	1.9134	3.000	1.6717	1.0469
185.0	5.7565	4.8840	54.0	3.8679	3.1970	12.500	2.4643	1.8853	2.900	1.6580	1.0304
180.0	5.7053	4.8386	52.0	3.8215	3.1551	12.000	2.4348	1.8564	2.800	1.6441	1.0136
175.0	5.6530	4.7925	50.0	3.7745	3.1121	11.500	2.4047	1.8267	2.700	1.6299	0.9962
170.0	5.5998	4.7454	48.0	3.7259	3.0679	11.000	2.3737	1.7960	2.600	1.6154	0.9783
165.0	5.5456	4.6973	46.0	3.6761	3.0224	10.500	2.3418	1.7643	2.500	1.6006	0.9599
160.0	5.4902	4.6483	44.0	3.6247	2.9756	10.000	2.3089	1.7316	2.400	1.5855	0.9409
155.0	5.4337	4.5983	42.0	3.5719	2.9273	9.800	2.2955	1.7181	2.300	1.5700	0.9213
150.0	5.3760	4.5471	41.0	3.5449	2.9025	9.600	2.2819	1.7045	2.200	1.5542	0.9009
145.0	5.3170	4.4948	40.0	3.5174	2.8773	9.400	2.2681	1.6906	2.100	1.5380	0.8798
140.0	5.2567	4.4412	39.0	3.4895	2.8517	9.200	2.2542	1.6766	2.000	1.5214	0.8579
135.0	5.1949	4.3864	38.0	3.4611	2.8257	9.000	2.2400	1.6623	1.900	1.5043	0.8350
130.0	5.1316	4.3301	37.0	3.4322	2.7991	8.800	2.2257	1.6478	1.800	1.4868	0.8112
125.0	5.0667	4.2724	36.0	3.4028	2.7721	8.600	2.2112	1.6331	1.700	1.4688	0.7862
120.0	5.0000	4.2131	35.0	3.3729	2.7445	8.400	2.1964	1.6181	1.600	1.4503	0.7599
115.0	4.9315	4.1521	34.0	3.3425	2.7164	8.200	2.1815	1.6029	1.500	1.4311	0.7322
110.0	4.8610	4.0892	33.0	3.3114	2.6878	8.000	2.1663	1.5874	1.400	1.4114	0.7028
108.0	4.8322	4.0636	32.0	3.2798	2.6585	7.800	2.1509	1.5716	1.350	1.4012	0.6874
106.0	4.8031	4.0376	31.0	3.2475	2.6286	7.600	2.1353	1.5555	1.300	1.3909	0.6716
104.0	4.7735	4.0112	30.0	3.2145	2.5980	7.400	2.1193	1.5391	1.250	1.3804	0.6551
102.0	4.7437	3.9846	29.0	3.1808	2.5667	7.200	2.1032	1.5223	1.200	1.3697	0.6380
100.0	4.7134	3.9575	28.0	3.1463	2.5347	7.000	2.0867	1.5053	1.150	1.3588	0.6203
98.0	4.6827	3.9301	27.0	3.1111	2.5018	6.800	2.0700	1.4879	1.100	1.3477	0.6018
96.0	4.6516	3.9024	26.0	3.0750	2.4681	6.600	2.0530	1.4701	1.050	1.3363	0.5825
94.0	4.6201	3.8742	25.0	3.0380	2.4335	6.400	2.0357	1.4519	1.000	1.3247	0.5623
92.0	4.5882	3.8456	24.0	3.0000	2.3979	6.200	2.0180	1.4333	0.950	1.3129	0.5410
90.0	4.5558	3.8166	23.0	2.9610	2.3613	6.000	2.0000	1.4142	0.900	1.3007	0.5186
88.0	4.5229	3.7871	22.0	2.9209	2.3236	5.800	1.9816	1.3947	0.850	1.2883	0.4948
86.0	4.4895	3.7572	21.0	2.8797	2.2846	5.600	1.9629	1.3747	0.800	1.2756	0.4694
84.0	4.4556	3.7269	20.0	2.8371	2.2443	5.400	1.9437	1.3541	0.750	1.2626	0.4422
82.0	4.4212	3.6960	19.5	2.8154	2.2237	5.200	1.9242	1.3330	0.700	1.2492	0.4127
80.0	4.3862	3.6646	19.0	2.7932	2.2026	5.000	1.9042	1.3112	0.650	1.2354	0.3803
78.0	4.3507	3.6327	18.5	2.7707	2.1812	4.800	1.8837	1.2889	0.600	1.2212	0.3442
76.0	4.3145	3.6002	18.0	2.7478	2.1594	4.600	1.8627	1.2658	0.550	1.2066	0.3031
74.0	4.2777	3.5671	17.5	2.7245	2.1371	4.400	1.8411	1.2419	0.500	1.1915	0.2544
72.0	4.2403	3.5334	17.0	2.7008	2.1144	4.200	1.8190	1.2172	0.450	1.1759	0.1924
70.0	4.2022	3.4991	16.5	2.6766	2.0913	4.000	1.7963	1.1917	0.400	1.1597	0.0932
68.0	4.1633	3.4641	16.0	2.6520	2.0676	3.800	1.7729	1.1651	0.390	1.1564	0.0732
66.0	4.1237	3.4284	15.5	2.6269	2.0434	3.600	1.7489	1.1375	0.385	1.1547	0.0076

68.0	4.1633	3.4641		16.0	2.6520	2.0676		3.800	1.7729	1.1651		0.390	1.1594	0.0342	
66.0	4.1237	3.4284		15.5	2.6269	2.0434		3.600	1.7489	1.1375		0.385	1.1547	0.0076	

PORTION II

Values of u_1, u_2, and u_3 for v equal to or less than 0.3849
When v is negative, values given for u_1, u_2, and u_3 take a negative sign.

v	u_1	u_2	u_3	v	u_1	u_2	u_3	v	u_1	u_2	u_3	v	u_1	u_2	u_3
				0.3510	1.1433	0.4311	0.7121	0.254	1.1087	0.2747	0.8339	0.156	1.0704	0.1601	0.9103
$(2/9)\sqrt{3}$	$(2/3)\sqrt{3}$	$(1/3)\sqrt{3}$	$(1/3)\sqrt{3}$	0.3500	1.1429	0.4289	0.7140	0.252	1.1079	0.2722	0.8357	0.154	1.0696	0.1579	0.9116
				0.3480	1.1422	0.4245	0.7177	0.250	1.1072	0.2696	0.8376	0.152	1.0587	0.1558	0.9130
				0.3460	1.1415	0.4202	0.7213	0.248	1.1064	0.2670	0.8394	0.150	1.0679	0.1536	0.9143
0.3849	1.1547	0.5770	0.5777	0.3440	1.1408	0.4160	0.7249	0.246	1.1057	0.2645	0.8412	0.148	1.0671	0.1515	0.9156
0.3848	1.1547	0.5697	0.5849												
0.3847	1.1546	0.5666	0.5881	0.3420	1.1402	0.4119	0.7283	0.244	1.1049	0.2620	0.8429	0.146	1.0663	0.1493	0.9169
0.3846	1.1546	0.5654	0.5905	0.3400	1.1395	0.4078	0.7316	0.242	1.1042	0.2595	0.8447	0.144	1.0654	0.1472	0.9182
0.3845	1.1546	0.5621	0.5925	0.3380	1.1388	0.4039	0.7349	0.240	1.1034	0.2570	0.8464	0.142	1.0646	0.1451	0.9196
				0.3360	1.1381	0.4000	0.7381	0.238	1.1027	0.2545	0.8482	0.140	1.0638	0.1429	0.9209
0.3844	1.1545	0.5603	0.5943	0.3340	1.1374	0.3962	0.7412	0.236	1.1019	0.2520	0.8499	0.138	1.0629	0.1408	0.9221
0.3843	1.1545	0.5586	0.5959												
0.3842	1.1545	0.5571	0.5973	0.3320	1.1367	0.3924	0.7443	0.234	1.1011	0.2495	0.8516	0.136	1.0621	0.1387	0.9234
0.3841	1.1544	0.5557	0.5987	0.3300	1.1360	0.3888	0.7472	0.232	1.1004	0.2471	0.8533	0.134	1.0613	0.1365	0.9247
0.3840	1.1544	0.5544	0.6000	0.3280	1.1353	0.3851	0.7502	0.230	1.0996	0.2446	0.8550	0.132	1.0604	0.1344	0.9260
				0.3260	1.1346	0.3815	0.7531	0.228	1.0989	0.2422	0.8566	0.130	1.0596	0.1323	0.9273
0.3835	1.1542	0.5487	0.6056	0.3240	1.1339	0.3780	0.7559	0.226	1.0981	0.2398	0.8583	0.128	1.0587	0.1302	0.9285
0.3830	1.1541	0.5439	0.6102												
0.3525	1.1539	0.5397	0.6142	0.3220	1.1332	0.3745	0.7587	0.224	1.0973	0.2374	0.8600	0.126	1.0579	0.1281	0.9298
0.3820	1.1537	0.5359	0.6178	0.3200	1.1325	0.3711	0.7614	0.222	1.0966	0.2350	0.8616	0.124	1.0570	0.1260	0.9310
0.3815	1.1536	0.5325	0.6211	0.3180	1.1318	0.3677	0.7641	0.220	1.0958	0.2326	0.8632	0.122	1.0562	0.1239	0.9323
				0.3160	1.1311	0.3644	0.7667	0.218	1.0950	0.2302	0.8648	0.120	1.0553	0.1218	0.9335
0.3810	1.1534	0.5292	0.6242	0.3140	1.1304	0.3611	0.7693	0.216	1.0943	0.2278	0.8664	0.118	1.0545	0.1197	0.9348
0.3805	1.1532	0.5262	0.6270												
0.3800	1.1531	0.5233	0.6298	0.3120	1.1297	0.3578	0.7719	0.214	1.0935	0.2255	0.8680	0.116	1.0536	0.1176	0.9360
0.3790	1.1527	0.5180	0.6348	0.3100	1.1290	0.3546	0.7744	0.212	1.0927	0.2231	0.8696	0.114	1.0528	0.1155	0.9372
0.3780	1.1524	0.5130	0.6394	0.3080	1.1283	0.3514	0.7769	0.210	1.0919	0.2208	0.8712	0.112	1.0519	0.1135	0.9384
				0.3060	1.1276	0.3482	0.7793	0.208	1.0912	0.2184	0.8727	0.110	1.0510	0.1114	0.9396
0.3770	1.1521	0.5084	0.6436	0.3040	1.1268	0.3451	0.7817	0.206	1.0904	0.2161	0.8743	0.108	1.0502	0.1093	0.9409
0.3760	1.1517	0.5041	0.6476												
0.3750	1.1514	0.5000	0.6514	0.3020	1.1261	0.3420	0.7841	0.204	1.0896	0.2138	0.8758	0.106	1.0493	0.1072	0.9421
0.3740	1.1511	0.4961	0.6550	0.3000	1.1254	0.3389	0.7865	0.202	1.0888	0.2115	0.8774	0.104	1.0484	0.1052	0.9433
0.3730	1.1507	0.4923	0.6584	0.2980	1.1247	0.3359	0.7888	0.200	1.0880	0.2091	0.8789	0.102	1.0476	0.1031	0.9445
				0.2960	1.1240	0.3329	0.7911	0.198	1.0872	0.2059	0.8804	0.100	1.0467	0.1010	0.9456
0.3720	1.1504	0.4887	0.6616	0.2940	1.1233	0.3299	0.7934	0.196	1.0865	0.2046	0.8819	0.098	1.0445	0.0989	0.9486
0.3710	1.1500	0.4853	0.6648												
0.3700	1.1497	0.4819	0.6678	0.2920	1.1226	0.3270	0.7956	0.194	1.0857	0.2023	0.8834	0.096	1.0423	0.0907	0.9515
0.3690	1.1494	0.4787	0.6707	0.2900	1.1218	0.3240	0.7978	0.192	1.0849	0.2000	0.8849	0.085	1.0401	0.0855	0.9544
0.3680	1.1490	0.4755	0.6735	0.2880	1.1211	0.3211	0.8000	0.190	1.0841	0.1977	0.8864	0.080	1.0378	0.0805	0.9573
				0.2860	1.1204	0.3182	0.8022	0.188	1.0833	0.1955	0.8878	0.075	1.0355	0.0754	0.9602
0.3670	1.1487	0.4725	0.6762	0.2840	1.1197	0.3154	0.8043	0.186	1.0825	0.1932	0.8893	0.070	1.0333	0.0703	0.9630
0.3660	1.1484	0.4695	0.6789												
0.3650	1.1480	0.4666	0.6815	0.2820	1.1189	0.3125	0.8064	0.184	1.0817	0.1910	0.8907	0.065	1.0310	0.0653	0.9658
0.3640	1.1477	0.4637	0.6840	0.2800	1.1182	0.3097	0.8085	0.182	1.0809	0.1887	0.8922	0.060	1.0287	0.0602	0.9685
0.3630	1.1473	0.4609	0.6864	0.2780	1.1175	0.3069	0.8106	0.180	1.0801	0.1865	0.8936	0.055	1.0264	0.0552	0.9713
				0.2760	1.1168	0.3041	0.8126	0.178	1.0793	0.1843	0.8951	0.050	1.0241	0.0501	0.9740
0.3620	1.1470	0.4582	0.6888	0.2740	1.1160	0.3014	0.8147	0.176	1.0785	0.1820	0.8965	0.045	1.0218	0.0451	0.9767
0.3610	1.1467	0.4555	0.6911												
0.3600	1.1463	0.4529	0.6934	0.2720	1.1153	0.2986	0.8167	0.174	1.0777	0.1798	0.8979	0.040	1.0194	0.0401	0.9794
0.3590	1.1460	0.4503	0.6957	0.2700	1.1146	0.2959	0.8187	0.172	1.0769	0.1776	0.8993	0.035	1.0171	0.0350	0.9820
0.3580	1.1456	0.4478	0.6979	0.2680	1.1138	0.2932	0.8206	0.170	1.0761	0.1754	0.9007	0.030	1.0147	0.0300	0.9846
				0.2660	1.1131	0.2905	0.8226	0.168	1.0753	0.1732	0.9021	0.025	1.0123	0.0250	0.9873
0.3570	1.1453	0.4453	0.7000	0.2640	1.1124	0.2879	0.8245	0.166	1.0745	0.1710	0.9035	0.020	1.0099	0.0200	0.9898
0.3560	1.1450	0.4429	0.7021												
0.3550	1.1446	0.4404	0.7042	0.2620	1.1116	0.2852	0.8264	0.164	1.0737	0.1688	0.9049	0.015	1.0074	0.0150	0.9924
0.3540	1.1443	0.4381	0.7062	0.2600	1.1109	0.2826	0.8283	0.162	1.0728	0.1666	0.9062	0.010	1.0050	0.0100	0.9950
0.3530	1.1439	0.4357	0.7082	0.2580	1.1101	0.2799	0.8302	0.160	1.0720	0.1644	0.9076	0.005	1.0025	0.0050	0.9975
0.3520	1.1436	0.4334	0.7102	0.2560	1.1094	0.2773	0.8321	0.158	1.0712	0.1623	0.9089	0.000	1.0000	0.0000	1.0000

Table III—Case III: Slope at Inflection Point is Positive

$b - (a^2/3)$ = a positive quantity
When v is negative, values given for u_1 and u_4 take a negative sign.

v	u_1	u_4	v	u_1	u_4	v	u_1	u_4	v	u_1	u_4
230.0	6.0725	5.3532	11.60	2.1167	2.0881	1.180	0.7530	1.1938	0.278	0.2604	1.0251
225.0	6.0274	5.3148	11.40	2.1027	2.0775	1.160	0.7456	1.1903	0.276	0.2587	1.0248
220.0	5.9816	5.2759	11.20	2.0886	2.0668	1.140	0.7380	1.1868	0.274	0.2570	1.0245
215.0	5.9351	5.2363	11.00	2.0743	2.0560	1.120	0.7304	1.1833	0.272	0.2554	1.0242
210.0	5.8878	5.1962	10.80	2.0599	2.0451	1.100	0.7226	1.1797	0.270	0.2537	1.0238
205.0	5.8398	5.1554	10.60	2.0452	2.0340	1.080	0.7148	1.1761	0.268	0.2520	1.0235
200.0	5.7910	5.1139	10.40	2.0303	2.0228	1.060	0.7068	1.1725	0.266	0.2503	1.0232
195.0	5.7414	5.0718	10.20	2.0153	2.0115	1.040	0.6988	1.1689	0.264	0.2486	1.0229
190.0	5.6909	5.0289	10.00	2.0000	2.0000	1.020	0.6906	1.1652	0.262	0.2469	1.0226
185.0	5.6395	4.9853	9.80	1.9845	1.9884	1.000	0.6823	1.1615	0.260	0.2452	1.0223
180.0	5.5872	4.9409	9.60	1.9688	1.9766	0.980	0.6739	1.1579	0.258	0.2436	1.0220
175.0	5.5339	4.8957	9.40	1.9528	1.9647	0.960	0.6654	1.1542	0.256	0.2419	1.0217
170.0	5.4795	4.8496	9.20	1.9366	1.9527	0.940	0.6567	1.1504	0.254	0.2402	1.0214
165.0	5.4240	4.8026	9.00	1.9202	1.9404	0.920	0.6480	1.1467	0.252	0.2384	1.0211
160.0	5.3674	4.7547	8.80	1.9035	1.9280	0.900	0.6390	1.1429	0.250	0.2367	1.0208
155.0	5.3096	4.7058	8.60	1.8865	1.9155	0.880	0.6300	1.1391	0.248	0.2350	1.0205
150.0	5.2506	4.6558	8.40	1.8692	1.9027	0.870	0.6254	1.1373	0.246	0.2333	1.0202
145.0	5.1901	4.6047	8.20	1.8516	1.8898	0.860	0.6208	1.1354	0.244	0.2316	1.0199
140.0	5.1283	4.5524	8.00	1.8338	1.8767	0.850	0.6161	1.1334	0.242	0.2299	1.0196
135.0	5.0650	4.4989	7.80	1.8156	1.8634	0.840	0.6114	1.1315	0.240	0.2281	1.0193
130.0	5.0000	4.4441	7.60	1.7970	1.8498	0.830	0.6067	1.1296	0.238	0.2264	1.0190
125.0	4.9333	4.3879	7.40	1.7781	1.8361	0.820	0.6019	1.1277	0.236	0.2247	1.0188
120.0	4.8648	4.3301	7.20	1.7589	1.8221	0.810	0.5971	1.1258	0.234	0.2229	1.0185
115.0	4.7944	4.2708	7.00	1.7392	1.8079	0.800	0.5923	1.1239	0.232	0.2212	1.0182
110.0	4.7219	4.2097	6.80	1.7191	1.7935	0.790	0.5874	1.1219	0.230	0.2194	1.0179
108.0	4.6922	4.1848	6.60	1.6987	1.7788	0.780	0.5824	1.1200	0.228	0.2177	1.0176
106.0	4.6622	4.1596	6.40	1.6777	1.7638	0.770	0.5775	1.1181	0.226	0.2159	1.0173
104.0	4.6318	4.1340	6.20	1.6563	1.7486	0.760	0.5724	1.1161	0.224	0.2142	1.0171
102.0	4.6010	4.1081	6.00	1.6344	1.7330	0.750	0.5674	1.1142	0.222	0.2124	1.0168
100.0	4.5698	4.0819	5.80	1.6119	1.7172	0.740	0.5623	1.1122	0.220	0.2107	1.0165
98.0	4.5381	4.0554	5.60	1.5889	1.7010	0.730	0.5571	1.1103	0.218	0.2089	1.0162
96.0	4.5061	4.0285	5.40	1.5652	1.6845	0.720	0.5519	1.1084	0.216	0.2071	1.0160
94.0	4.4735	4.0012	5.30	1.5532	1.6761	0.710	0.5466	1.1064	0.214	0.2053	1.0157
92.0	4.4405	3.9735	5.20	1.5410	1.6676	0.700	0.5414	1.1044	0.212	0.2036	1.0154
90.0	4.4070	3.9454	5.10	1.5286	1.6590	0.690	0.5360	1.1025	0.210	0.2018	1.0152
88.0	4.3730	3.9170	5.00	1.5160	1.6503	0.680	0.5306	1.1005	0.208	0.2000	1.0149
86.0	4.3385	3.8880	4.90	1.5032	1.6416	0.670	0.5252	1.0986	0.206	0.1982	1.0146
84.0	4.3034	3.8587	4.80	1.4903	1.6327	0.660	0.5197	1.0966	0.204	0.1964	1.0144
82.0	4.2678	3.8289	4.70	1.4771	1.6237	0.650	0.5141	1.0946	0.202	0.1946	1.0141
80.0	4.2315	3.7986	4.60	1.4638	1.6146	0.640	0.5085	1.0927	0.200	0.1928	1.0138
78.0	4.1947	3.7678	4.50	1.4502	1.6054	0.630	0.5029	1.0907	0.198	0.1910	1.0136
76.0	4.1571	3.7365	4.40	1.4364	1.5961	0.620	0.4971	1.0887	0.196	0.1892	1.0133
74.0	4.1190	3.7046	4.30	1.4224	1.5866	0.610	0.4914	1.0868	0.194	0.1874	1.0131
72.0	4.0801	3.6722	4.20	1.4081	1.5770	0.600	0.4855	1.0848	0.192	0.1856	1.0128
70.0	4.0404	3.6392	4.10	1.3936	1.5673	0.590	0.4797	1.0828	0.190	0.1838	1.0126
68.0	4.0000	3.6056	4.00	1.3788	1.5575	0.580	0.4737	1.0809	0.188	0.1820	1.0123
66.0	3.9588	3.5713	3.90	1.3637	1.5475	0.570	0.4677	1.0789	0.186	0.1802	1.0121
64.0	3.9167	3.5363	3.80	1.3484	1.5374	0.560	0.4616	1.0770	0.184	0.1783	1.0119
62.0	3.8737	3.5006	3.70	1.3327	1.5271	0.550	0.4555	1.0750	0.182	0.1765	1.0116
60.0	3.8297	3.4641	3.60	1.3168	1.5167	0.540	0.4493	1.0730	0.180	0.1747	1.0114
			3.50	1.3005	1.5061	0.530	0.4430	1.0711	0.178	0.1728	1.0111
						0.520	0.4367	1.0691	0.176	0.1710	1.0109

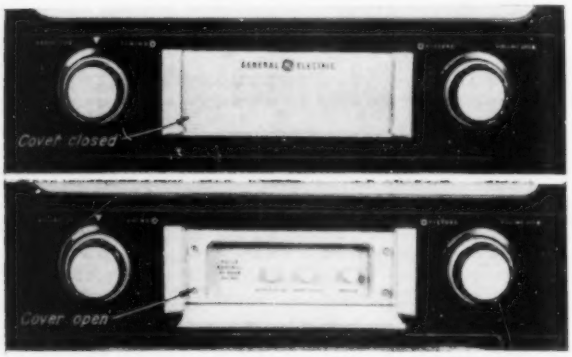
60.0	3.8297	3.4641	3.70	1.3327	1.5271	0.550	0.4555	1.0750	0.184	0.1783	1.0119
			3.60	1.3168	1.5167	0.540	0.4493	1.0730	0.182	0.1765	1.0116
58.0	3.7848	3.4269	3.50	1.3005	1.5061	0.530	0.4430	1.0711	0.178	0.1728	1.0111
56.0	3.7388	3.3888	3.40	1.2839	1.4954	0.520	0.4367	1.0691	0.176	0.1710	1.0109
54.0	3.6916	3.3498	3.30	1.2668	1.4845	0.510	0.4303	1.0672	0.174	0.1692	1.0107
52.0	3.6432	3.3098	3.20	1.2495	1.4734	0.500	0.4239	1.0652	0.172	0.1673	1.0104
50.0	3.5936	3.2688	3.10	1.2316	1.4621	0.495	0.4206	1.0643	0.170	0.1655	1.0102
48.0	3.5425	3.2268	3.00	1.2134	1.4506	0.490	0.4173	1.0633	0.168	0.1636	1.0100
46.0	3.4900	3.1836	2.95	1.2041	1.4448	0.485	0.4140	1.0623	0.166	0.1618	1.0098
45.0	3.4632	3.1615	2.90	1.1947	1.4389	0.480	0.4107	1.0614	0.164	0.1599	1.0095
44.0	3.4360	3.1392	2.85	1.1852	1.4330	0.475	0.4074	1.0604	0.162	0.1581	1.0093
43.0	3.4083	3.1165	2.80	1.1755	1.4270	0.470	0.4040	1.0595	0.160	0.1562	1.0091
42.0	3.3802	3.0934	2.75	1.1658	1.4210	0.465	0.4007	1.0585	0.158	0.1543	1.0089
41.0	3.3516	3.0700	2.70	1.1558	1.4149	0.460	0.3973	1.0575	0.156	0.1525	1.0087
40.0	3.3225	3.0462	2.65	1.1458	1.4088	0.455	0.3939	1.0566	0.154	0.1506	1.0085
39.0	3.2929	3.0220	2.60	1.1356	1.4026	0.450	0.3905	1.0556	0.152	0.1487	1.0083
38.0	3.2629	2.9974	2.55	1.1252	1.3963	0.445	0.3870	1.0547	0.150	0.1468	1.0081
37.0	3.2322	2.9724	2.50	1.1147	1.3900	0.440	0.3836	1.0537	0.148	0.1450	1.0078
36.0	3.2010	2.9470	2.45	1.1041	1.3836	0.435	0.3801	1.0528	0.146	0.1431	1.0076
35.0	3.1692	2.9211	2.40	1.0933	1.3771	0.430	0.3766	1.0518	0.144	0.1412	1.0074
34.0	3.1368	2.8947	2.35	1.0823	1.3706	0.425	0.3731	1.0509	0.142	0.1393	1.0073
33.0	3.1037	2.8678	2.30	1.0711	1.3640	0.420	0.3695	1.0500	0.140	0.1374	1.0071
32.0	3.0698	2.8404	2.25	1.0598	1.3573	0.415	0.3660	1.0490	0.138	0.1355	1.0069
31.0	3.0353	2.8124	2.20	1.0482	1.3506	0.410	0.3624	1.0481	0.136	0.1336	1.0067
30.0	3.0000	2.7839	2.15	1.0365	1.3438	0.405	0.3588	1.0472	0.134	0.1317	1.0065
29.0	2.9639	2.7547	2.10	1.0245	1.3369	0.400	0.3552	1.0462	0.133	0.1308	1.0064
28.0	2.9269	2.7249	2.05	1.0124	1.3299	0.395	0.3516	1.0453	0.132	0.1298	1.0063
27.0	2.8889	2.6943	2.00	1.0000	1.3229	0.390	0.3479	1.0444	0.131	0.1289	1.0062
26.0	2.8500	2.6631	1.95	0.9874	1.3157	0.385	0.3442	1.0435	0.130	0.1279	1.0061
25.0	2.8101	2.6310	1.90	0.9745	1.3085	0.380	0.3405	1.0426	0.129	0.1270	1.0060
24.0	2.7690	2.5982	1.85	0.9614	1.3012	0.375	0.3368	1.0417	0.128	0.1260	1.0059
23.5	2.7480	2.5814	1.80	0.9480	1.2938	0.370	0.3331	1.0408	0.127	0.1250	1.0058
23.0	2.7267	2.5644	1.75	0.9343	1.2864	0.365	0.3293	1.0399	0.126	0.1241	1.0058
22.5	2.7051	2.5472	1.70	0.9204	1.2788	0.360	0.3255	1.0390	0.125	0.1231	1.0057
22.0	2.6832	2.5297	1.68	0.9147	1.2757	0.355	0.3217	1.0381	0.124	0.1222	1.0056
21.5	2.6609	2.5120	1.66	0.9090	1.2727	0.350	0.3179	1.0372	0.123	0.1212	1.0055
21.0	2.6382	2.4940	1.64	0.9032	1.2696	0.345	0.3140	1.0363	0.122	0.1203	1.0054
20.5	2.6151	2.4757	1.62	0.8974	1.2665	0.340	0.3102	1.0354	0.121	0.1193	1.0053
20.0	2.5917	2.4572	1.60	0.8915	1.2634	0.335	0.3063	1.0346	0.120	0.1183	1.0052
19.5	2.5679	2.4383	1.58	0.8856	1.2602	0.330	0.3024	1.0337	0.119	0.1174	1.0052
19.0	2.5436	2.4192	1.56	0.8796	1.2571	0.325	0.2984	1.0329	0.118	0.1164	1.0051
18.5	2.5189	2.3997	1.54	0.8735	1.2539	0.320	0.2945	1.0320	0.117	0.1155	1.0050
18.0	2.4937	2.3799	1.52	0.8674	1.2507	0.315	0.2905	1.0312	0.116	0.1145	1.0049
17.5	2.4680	2.3597	1.50	0.8612	1.2475	0.310	0.2865	1.0303	0.115	0.1135	1.0048
17.0	2.4418	2.3392	1.48	0.8550	1.2443	0.308	0.2849	1.0300	0.114	0.1126	1.0047
16.5	2.4150	2.3182	1.46	0.8487	1.2411	0.306	0.2833	1.0297	0.113	0.1116	1.0047
16.0	2.3877	2.2969	1.44	0.8423	1.2378	0.304	0.2817	1.0293	0.112	0.1106	1.0046
15.5	2.3598	2.2752	1.42	0.8359	1.2345	0.302	0.2800	1.0290	0.111	0.1097	1.0045
15.0	2.3312	2.2530	1.40	0.8294	1.2312	0.300	0.2784	1.0287	0.110	0.1087	1.0044
14.5	2.3020	2.2303	1.38	0.8229	1.2279	0.298	0.2768	1.0283	0.109	0.1077	1.0043
14.0	2.2720	2.2071	1.36	0.8162	1.2246	0.296	0.2752	1.0280	0.108	0.1068	1.0043
13.5	2.2413	2.1835	1.34	0.8095	1.2213	0.294	0.2735	1.0277	0.107	0.1058	1.0042
13.0	2.2098	2.1592	1.32	0.8027	1.2179	0.292	0.2719	1.0274	0.106	0.1048	1.0041
12.8	2.1969	2.1494	1.30	0.7959	1.2145	0.290	0.2703	1.0270	0.105	0.1039	1.0040
12.6	2.1839	2.1394	1.28	0.7889	1.2111	0.288	0.2686	1.0267	0.104	0.1029	1.0040
12.4	2.1708	2.1294	1.26	0.7819	1.2077	0.286	0.2670	1.0264	0.103	0.1019	1.0039
12.2	2.1575	2.1192	1.24	0.7748	1.2043	0.284	0.2653	1.0261	0.102	0.1010	1.0038
12.0	2.1440	2.1090	1.22	0.7676	1.2008	0.282	0.2637	1.0257	0.101	0.1000	1.0037
11.8	2.1304	2.0986	1.20	0.7604	1.1973	0.280	0.2620	1.0254	0.100	0.0990	1.0037

Simple Controls Have Sales Appeal

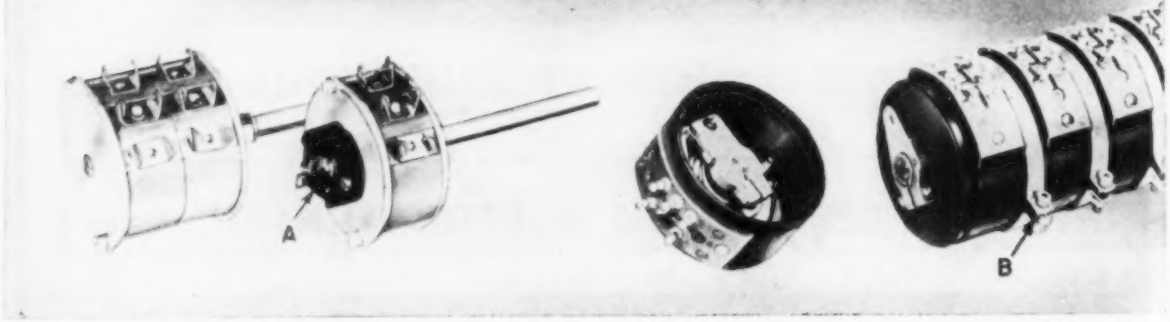
EDWIN DREWITZ
Design Consultant

From the customer's point of view, the most important parts of a control device are the external, visible elements. Regardless of what else he must understand about the machine, appliance or other product, he must be able to operate its controls correctly and with dispatch. Thus, simplicity can be just as important a design factor as function. This includes reducing the number of different elements that must be adjusted or interpreted as well as reducing the possibility for destructive error. Several solutions to specific control problems are shown to suggest how this simplification can be combined with improved overall appearance and lower costs—often in one bold stroke.

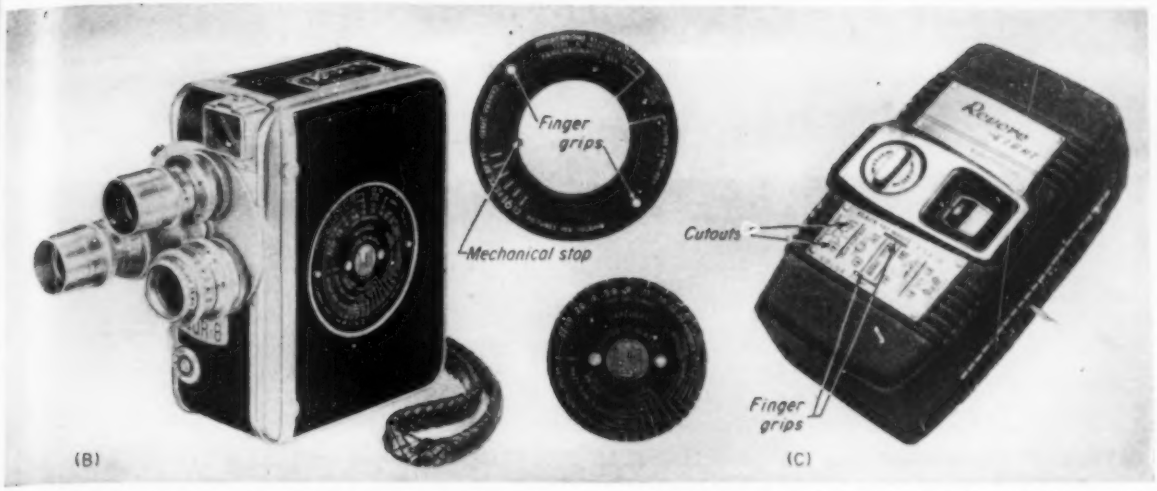
SINGLE ELEMENT CONTROLS are the simplest form of control devices. They provide only one function, service, or solution and can often be designed as fixed instruction plates. Camera (*A*) features a stationary etched and color filled exposure calculator that graphically illustrates dif-



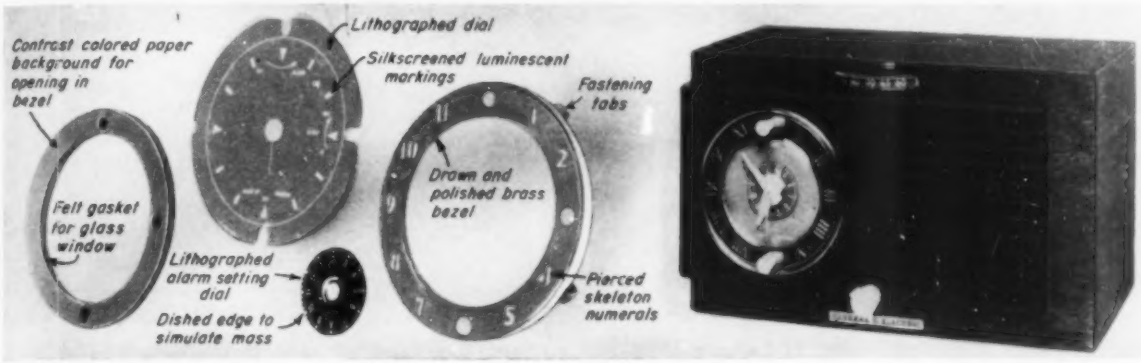
BY REDUCING the number of separate controls necessary, twin element types cut costs and promote sales. Thus, the TV industry is minimizing controls on receivers. A by-product is the concealment of secondary knobs at the rear of sets or under decorative escutcheons as above.



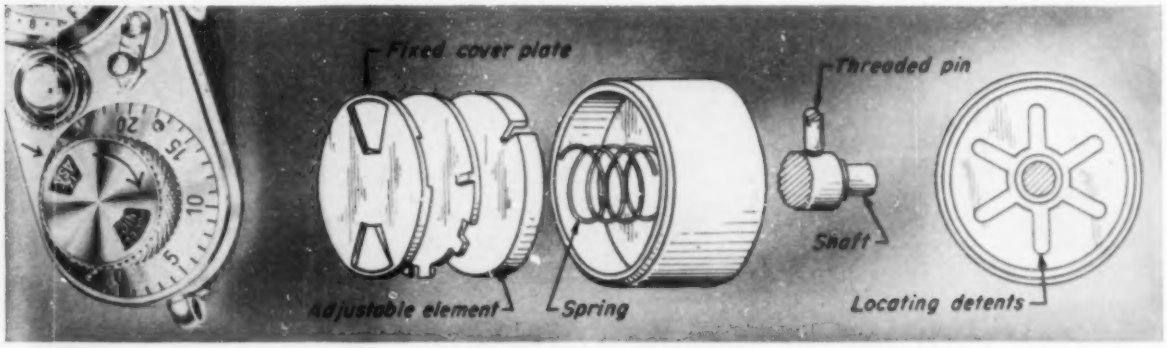
COMPACTLY GANGED RHEOSTAT and potentiometer units provide a means for adding the convenience of single knob control to multi-function elements. Units are available with integral on-off switches (*A*) or ganged combinations for single knob direction of several functional elements. Slip type ganging collars (*B*) facilitate individual phasing when greater flexibility is desired. Completely independent settings of several units can be accomplished with coaxial shafts. These rheostats have been designed to be used interchangeably in single or multiple types of installations.



ferent light conditions and supplies the correct lens openings for both color and black and white film. Design (*B*) adds more light and diaphragm combinations and a separate moving member for easy rotary slide rule operation. The outer disk has raised finger grips to facilitate orientation against the fixed central disk. The linear slide rule scheme shown at (*C*) is another approach. Also of twin etched plate design, this introduces, through appropriate cutouts, only one set of exposure solutions at a time. Selection is made by use of the finger grips.

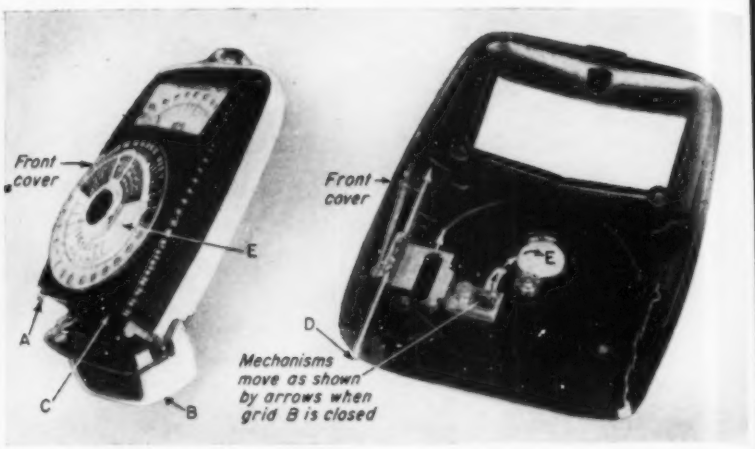

Contrast colored paper background for opening in bezel
Lithographed dial
Silkscreened luminescent markings
Fastening tabs
Felt gasket for glass window
Drawn and polished brass bezel
Lithographed alarm setting dial
Dished edge to simulate mass
Pierced skeleton numerals

ALARM RADIO shows how elaborate and apparently complex dial structures can be fabricated of numerous simple stampings, each marked and colored by different processes for maximum contrast. It also introduces an inexpensive but attractive tuning dial. Molded of transparent plastic material, the dial has a narrow groove at its periphery into which an inexpensive printed paper strip is inserted. This reduces tooling and procurement costs as well as permits modifications and/or appearance variations to be made with comparative ease and negligible expense.

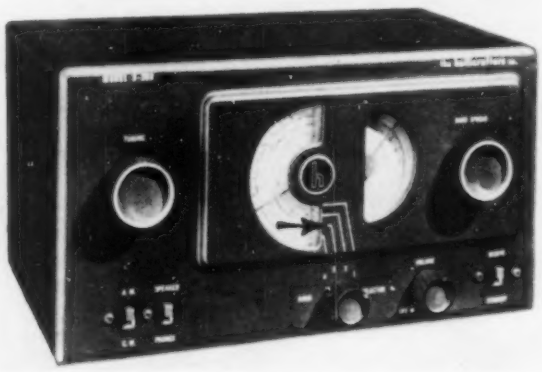


AN INDEXING SCHEME should be used to lock the selected control setting when vibration is a consideration or a positive guarantee against accidental misalignment is desired. Illustrated is a twin element film advance knob that features a built-in, independently adjustable memory device. The setting is not affected by rotation of the winding knob. Conversely, readjustment of the memory element does not disturb the knob's setting. Also practical in many cases, is a reverse, push type release in cooperation with a compression spring. (*continued on next page*)

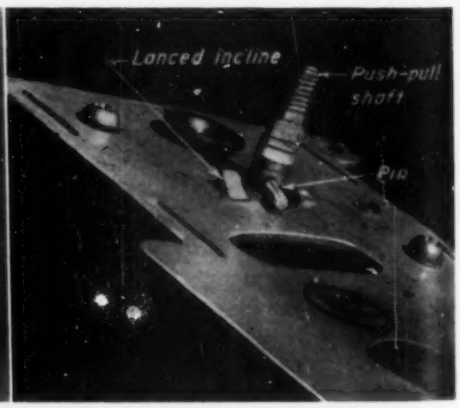
CAST, RAISED MARKINGS on this industrial type speed control are sanded for maximum contrast. The moveable pointer is cast and sanded.



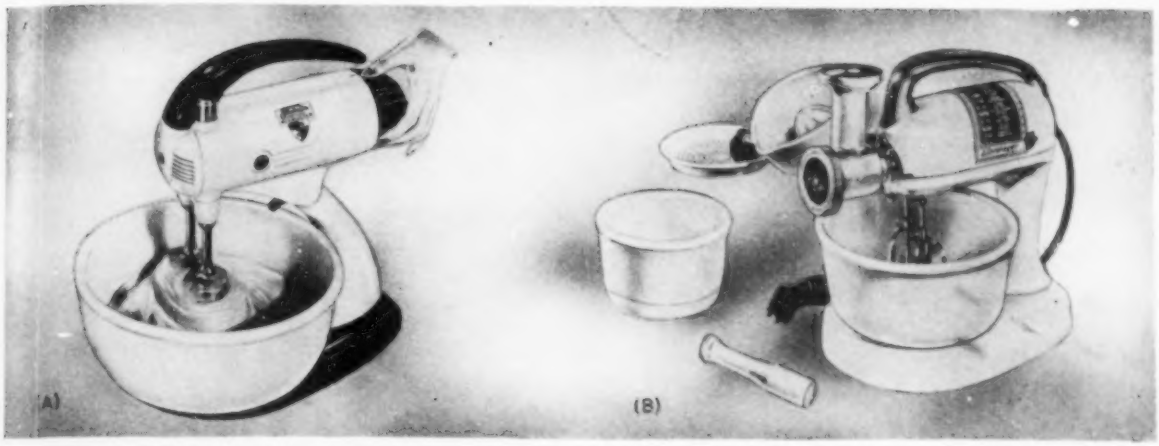
MECHANICAL INTERLOCKS improve operation of this exposure meter. A hinged grid compensates for the difference between reflected and direct light; push button (*A*) lowers grid (*B*) to expose photo cell (*C*) to full illumination. Spring loaded interlock (*D*) rotates scale (*E*) a set amount.



THESE TWIN ELEMENT CONTROLS have direct aids (see arrows) to improve legibility and accuracy. Contrastingly colored lines on the radio panel connect each of the four scales on the dial with the corresponding control knob position. The exposure meter uses solid-color blocks in the same way. Also, excessive parallax can be distracting and cause errors; pointers should have markings as close to the line-up edge as possible.

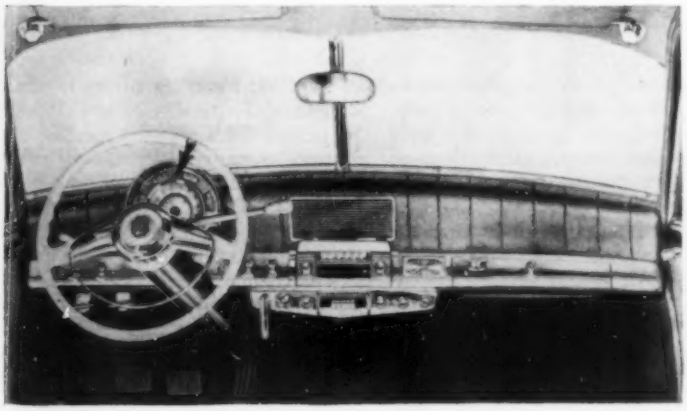


ANOTHER FORM of twin element device is this combination interval timer and cycle control for automatic washers. Varying degrees of automatism are accomplished with a universal, single-knob control. A snap switch energizes the main operating circuit and an electric clock mechanism; a push-pull switch is coupled to the drive shaft, as shown, for starting and stopping the cycle of operations. A push on the dial activates the control; the pinned shaft riding up an incline eventually returns the knob to the outer *off* position. A pilot light is also included.



SINCE THESE SINGLE ELEMENT controls are intended as sales features, they are accentuated to become the focal points of the entire units. Establishing ideal speed settings for different mixing duties not only promotes efficient operation, but also suggests reasons for buying a mixer. Note that the two manufacturers use fundamentally different units to accomplish the same result. In (A), the rotary dial is used, in (B) a sliding knob.

EQUALLY IMPORTANT as the functional simplicity of a control is its optimum location. This is particularly true when a series of different elements are required to operate a unit such as this automatic electric range. Maximum efficiency is assured by grouping all controls.



THE TREND toward single control centers is also apparent in automobile dash designs. Several instruments are often housed together. Thus, attention is riveted to one unit and all pertinent instruments are read at a glance. Unitized centers are also easier to illuminate; diffused lighting can be provided by acrylic rods that pipe light.

HINTS FOR DESIGNING MULTIPLE CONTROL UNITS

1. All controls should be positively identified and each related to its nameplate or marking. This is especially important when several similar push buttons or toggle levers are grouped closely together. Whenever possible, integrally marked push buttons should be used. Color coding the button or lever and its marking, or providing a decorative barrier or other distinctive area around each control and its plate are effective alternates. Colored pilot lights that indicate the on, off, or other condition of primary controls are also good sales features.

2. When more than one rotary knob or reciprocating lever is used in the same control package, they should operate in the same direction—the proper direction indicated by an arrow or similar device.

3. Avoid the need for more than one control station. Separate locations are often responsible for memory lapses and confusion on the part of the operator. Also, for maximum efficiency, group all controls in a convenient, completely visible location.

4. Select finishes, textures, and decoration processes that will stand up. This is particularly important on industrial equipment. Integral markings are better than separate dial plates that can get loose or rub off.

5. When designing for a tight price, evaluate all control components individually to get the maximum value and/or effect from each. For example, scales, indicators or dials, that are covered by a transparent window, can be fabricated of lighter gage materials and decorated by the less durable, although more versatile and economical printing processes. Savings, in turn, can be invested in more serviceable external elements that can be created in three dimensional plastics, acid etched metals, or die struck relief.

U. S. Rubber Co.

Fig. 1—Industrial parts molded, extruded or fabricated from rubber-styrene copolymers include ducts, piping, battery cases, trays and textile and electrical parts

New High Impact Styrenes

POLYSTYRENE'S WEAK SPOT in many engineering applications has been its low impact strength. Recent efforts by plastic manufacturers in blending styrene with rubber have produced compounds with much higher impact strength as well as greater ductility and improved low temperature properties. The light weight, high heat distortion point, chemical stability and good processing characteristics of polystyrene are generally retained.

The Bakelite Company and the U. S. Rubber Company have been very active in this field and each has recently produced modified styrenes with high impact strength. Their properties are listed in Table I.

The increase in impact strength obtained by modification is appreciable—up to six times that of regular polystyrene. However, in designing with these modified styrenes, other effects of modification must be considered.

The specific gravity, heat distortion point and flexural modulus are not seriously affected. Consequently the modified materials retain the advantages of light weight, good heat resistance and stiffness.

Properties that are affected adversely are tensile strength, flexural strength and water absorption. Tensile strength and flexural strength are only about half of regular polystyrene, although satisfactory for most applications in view of the gain in impact strength.

The much higher water absorption of modified materials adversely affects dimensional stability and electrical properties. This property must be considered in design of parts to be exposed to moisture. Tolerances can not be held as close because of the dimensional change that normally accompanies the absorption of moisture.

The chemical resistance of the rubber-modified polystyrenes is in general similar to regular polystyrene although not identical. A careful check on chemical resistance should be made prior to selection of the material.

For out of doors weathering resistance, the rubber modified materials are slightly poorer in the unpigmented state than polystyrene. There is little difference between modified and un-

Table I—Properties of Regular and Rubber-Modified Polystyrenes

	Bakelite Co. Materials				U. S. Rubber Material
	Polystyrene	QMS-151	QMS-152	QMS-155	Kralastic J
Specific Gravity	1.08	1.05–1.10	1.05–1.10	1.05–1.10	1.015
Water Absorption 24 hr., percent	0.03–0.04	0.12	0.12	0.12	0.3–0.4
Heat Distortion Point, F	180–190	178	178	183–187	170
Tensile Strength, psi	6,000–9,000	3,500–4,500	3,800–4,500	4,500–5,000	,100
Elongation in Tension, percent	1.5–2.7	10–25	10–20	10–30	
Flexural Strength, psi	10,000–15,000	6,000–6,500	6,000–6,500	6,000–7,000	5,400
Flexural Modulus, psi x 10^{-3}	300–350	300–350	300–350	200–250	140
Impact Strength					
Charpy, ft-lb./in. width 25 C.	3–6	15–20	15–20	20–35	
Charpy, ft-lb./in. width −25 C.		4–5	10–30	20–35	
Izod, ft-lb./in. of notch 25 C.	0.25–0.60	1–2	1.5–2.5	2.51–10	6–7
Izod, ft-lb./in. of notch −20 C.		.3–.4	.4–1.1	0.88–2.10	6.0
−40 C.					5.2
Power Factor					
60 cps, 10^3 cps, 10^6 cps	0.001–0.003	0.0007–0.006	0.0007–0.004	0.0024–0.0028	
Dielectric Constant					
60 cps, 10^3 cps, 10^6 cps	2.45–2.70	2.79–2.85	2.79–2.82	2.67–2.73	4.00–4.05
Loss Factor					
60 cps, 10^3 cps, 10^6 cps	0.00025–0.001	0.002–0.019	0.002–0.011	0.006–0.008	
Dielectric Strength, volts/mil					
Short Time		485	471	446	
Step by Step	400–600	437	449	434	340
Volume Resistivity, megohms		8.3×10^6	8.2×10^6	8.2×10^6	
Surface Resistivity, ohms		2.8×10^6	2.7×10^6	2.8×10^6	

The advantages of light weight, good chemical resistance and excellent processing characteristics of polystyrene have often been dampened by its poor impact strength. New styrene-rubber blends show marked improvement in toughness

modified polystyrene in the opaque pigmented types. The use of a weather resistant coating on pigmented styrenes, both modified and unmodified, should improve the applicability of other materials for out-of-doors service. A plastic with a weather resistant coating should certainly stand up better than painted steel since it would be much less subject to deterioration in case of coating failure caused by mechanical damage or improper application.

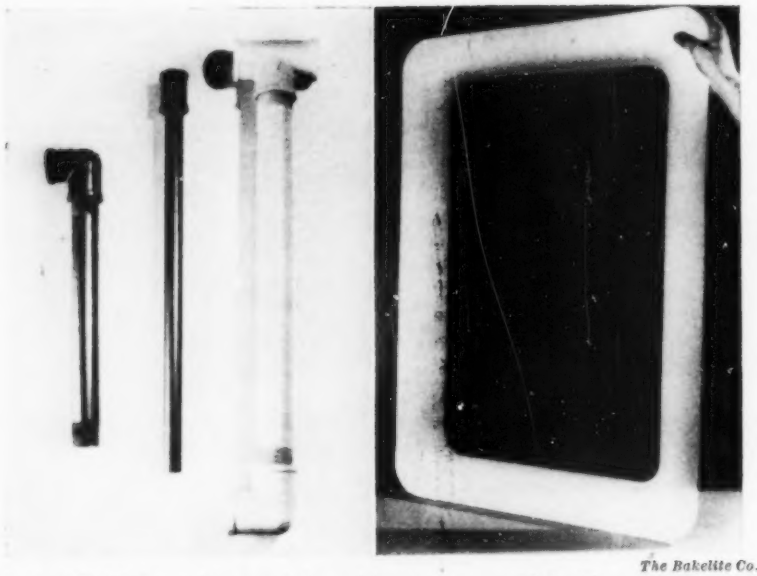
Specific Materials

Bakelite's rubber modified polystyrenes are designated as QMS 151, QMS 152 and QMS 153.

QMS-151, which is available in a variety of opaque colors (white to black) is a general purpose high-impact material since it can be molded at a higher rate per machine than the others and is suitable for a wide variety of applications between 20 F and 110 F. The toughness of this material is indicated by its high elongation and high modulus in tension, and its good Charpy and Izod impact strengths. In the flexural test failure is due to bending, further indicating the toughness of this material. Practically, the toughness is apparent by the manner in which tensile test specimens can be bent. Extrusion plasticity data indicate QMS-151 to be the most free-flowing of the three compounds.

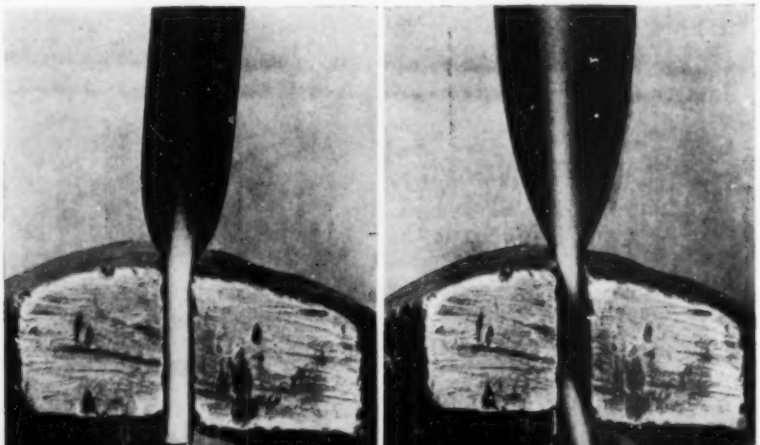
QMS-152 was developed for use in rigid pipe and fittings and is currently available only in black. It is superior to QMS-151 in toughness at both room temperature and sub-zero temperatures. Its extrusion characteristics are excellent and its injection molding characteristics good although it is not as free-flowing as QMS-151. Black pipe ½-in to 6-inch in diameter and molded pipe fittings were produced from QMS-152.

QMS-155 is by far the toughest of the three Bakelite high-impact polystyrenes as indicated by its high notched Izod impact strength, Charpy impact strength, low modulus of elasticity and resistance to abusive mechanical treatment at room temperature and sub-zero temperatures. It has excellent ex-



The Bakelite Co.

Fig. 2—(Right) Inner door panels for refrigerators are molded with a minimum wall thickness of about 0.100 inch and withstand repeated door slam tests. (Left) Extruded pipe of high impact styrene is light weight and is easily machined and threaded.



The Bakelite Co.

Fig. 3—The toughness of extruded styrene-rubber pipe is evidenced by its ability to resist cracking when squeezed and twisted in a vise, even at low temperatures.

trusion and molding characteristics though requiring slightly higher molding temperatures and pressures than QMS-151. The superior practical toughness of QMS-155 was demonstrated by ball drop tests and vise squeeze tests, Table II, on extruded tubing of QMS-152 and QMS-155 at normal room temperature and sub-zero temperatures.

QMS 151 is suitable for molding large parts with a relatively thin cross section, such as a refrigerator inner door panel. This part, Fig. 2, can not be molded from the 155 material even with increased injection pressures and longer molding cycles. QMS-155, however, can be used for relatively large parts if the cross section is not too thin. Refrigerator door frames, Fig. 2, were successfully molded from latter. A much higher cylinder temperature and cycle time was required.

U. S. Rubber's latest development in rubber plasticized styrene is designated as Kralastic J and is especially applicable at low temperatures.

While maintaining the general properties of rubber-styrene compositions it has the added advantage of retaining its toughness at temperatures as low as —40 to —50 C or —104 to —122F. Its impact strength at various temperatures is shown in Table I. There is only a slight drop in impact strength from 25 C to —40 C.

Fields of Application

The toughest grades are extruded into pipe and fittings or tubing for use in wells or farm water supply. The toughness of 0.8 inch tubing with a 0.125 wall thickness was demonstrated by its ability to withstand a 70 to 80 percent reduction in a vise, Fig. 3, without cracking—even at —5F. A one pound ball dropped 80 inches onto the tubing failed to crack it. Modified styrene pipe is light and easy to handle and can be machined and threaded on the job, resulting in savings in labor and installation costs. One hundred feet of one-inch pipe weighs only 14 lb compared to 168 lb for galvanized steel pipe.

Refrigerator parts are readily injection molded, swedged or blown from sheet. These parts include inner door panels, door frames and trays.

Battery cases injection molded from these compounds readily withstand rough handling even at low temperatures.

Other applications include strong wall moldings, toys, containers, ducts, housings for mechanical and electrical components. Small mechanical items such as cams and gears are also suitable for these materials.

Table II—(a) Height of Drop of 1 lb. Ball to Crack Extruded Tubing 0.8 in. Diam. x 0.125 in. Wall Thickness

	QMS-152	QMS-155
At Room Temperature	30–40 in.	80 in. +
At 0 C	10–12 in.	80 in. +
At —15 C	6– 8 in.	35 in.
At —23 C	2–4 in.	4–6 in.

(b) Reduction in Jaw Opening Before Cracking When Tubing 0.8 in. Dia. x 0.125 in. Wall Thickness is Squeezed in a Vise

	QMS-152	QMS-155
At Room Temperature	30–50%	70–80%
At 0 C	20–40%	70–80%
At —15 C	15–30%	70–80%
At —23 C	15–25%	50–80%

TECHNICAL NEWS

HONEY BEE is the first all metal one passenger light weight airplane. Weighing only 550 lb, the craft has a maximum flight speed of 120 mph and can climb at the rate of 1,100 fpm. Beecraft claims the airplane was designed and built in 60 days.

Designers Find New Ways To Use Aluminum

DESIGNERS HAVE ADDED two new "firsts" in the application of aluminum as production figures of the light metal continue to spiral. Recently Beecraft Associates, Inc., San Diego, Calif. announced the construction of the first all metal, single place, light weight airplane; while Grimston Astor Limited of England has completed the first all aluminum 60 ft ship.

Called the Honey Bee by its designers, the new airplane weighs only 550 pounds, has a 27 ft wingspan, and is 17 ft long. A 65 hp engine powers the aircraft at a top speed of 120 mph. Cruising speed is 110 mph at an altitude of 2,500 ft and the rate of climb is 1,100 fpm.

Despite several design innovations, Beecraft claims it took only 60 days to design and build the first Honey Bee. The airplane has an all-aluminum stressed skin, an unusual spring steel tricycle, landing gear, and a butterfly tail. Rudder pedals also steer the nose wheel, and a hydraulic braking system is incorporated for landing.

Beecraft anticipates that the new aircraft will be particularly useful for border, forestry, oil line, and wire patrols, as well as for individual business and pleasure flying trips.

Grimston Astor built the M. Y. Tonquin to demonstrate possible marine uses of stressed aluminum skins similar to those used in aircraft.

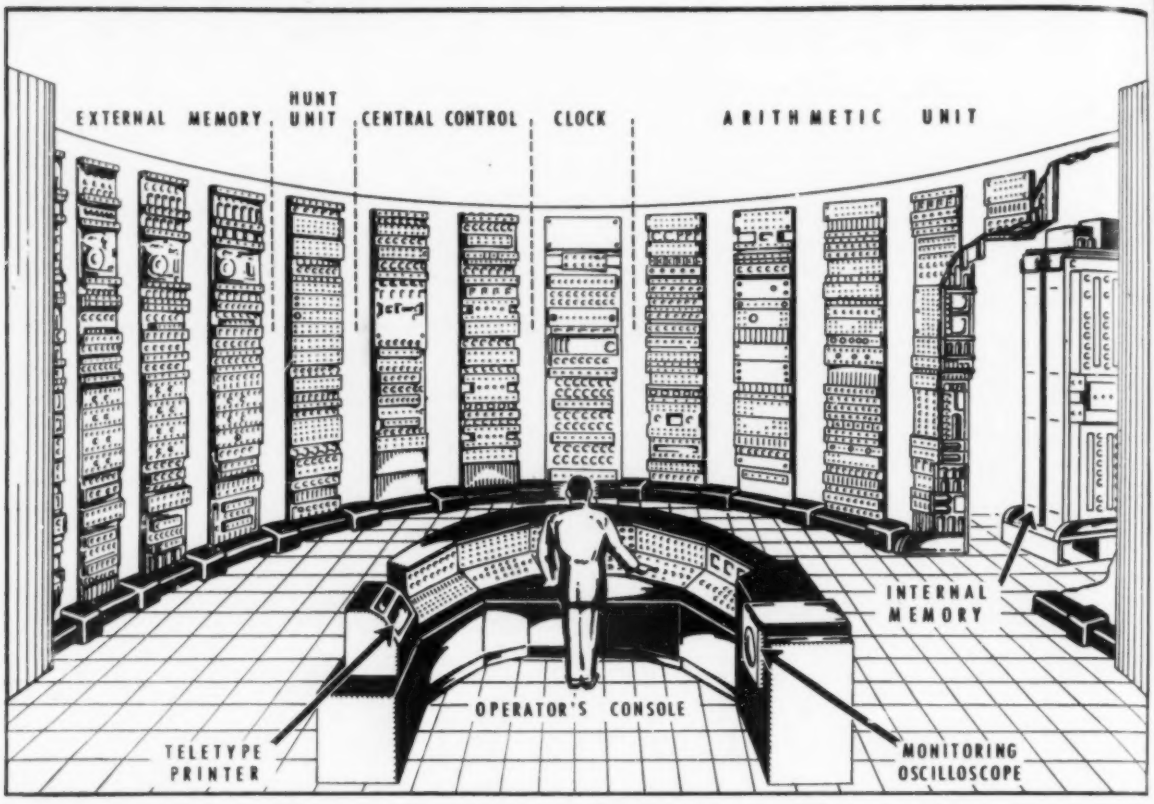
They shaped and joined the light alloy sheet that make up the hull in the flat state and added the transverse members. Then they pulled the sheets into shape so that resilience was imparted to the skin by the strain energy retained in the structure. Grimston Astor calls this technique the "two-way tension" system of construction.

In addition to reducing the displacement of the ship, the skin hull is responsible for considerable operating economies. In tests conducted for the British Government, the Tonquin traveled over 13 knots using half the power and fuel required by a wooden ship of the same size and design. Another advantage claimed for the light metal hull is that it displays better resistance to marine organisms than conventional materials.

Because of this new hull, the ship travels 1.2 nautical miles per gallon of fuel at the normal cruising speed of 12 knots. The twin Foden engines develop 104 hp at 1,800 rpm for continuous service and are capable of developing 120 hp at 2,000 rpm in intermittent service.

Aluminum for shipboard use got its biggest impetus from designers of the U.S.S. United States when details of that ocean liner were released. However, the Tonquin not only has extensive use of aluminum on the interior, but it is the largest ship afloat with an aluminum skin hull.

M. Y. TONQUIN is the largest ship ever built with aluminum skin hulls. Extensive use of aluminum inside and outside reduces displacement to 14 tons.



SCHEMATIC LAYOUT OF RAYDAC indicates locations of various parts in this new giant calculator. Electronic circuits use 5,000 miniature vacuum tubes and 18,000 germanium diodes. Scientists will use computer to analyze guided missile flight problems.

More New Computers to Solve Defense Problems

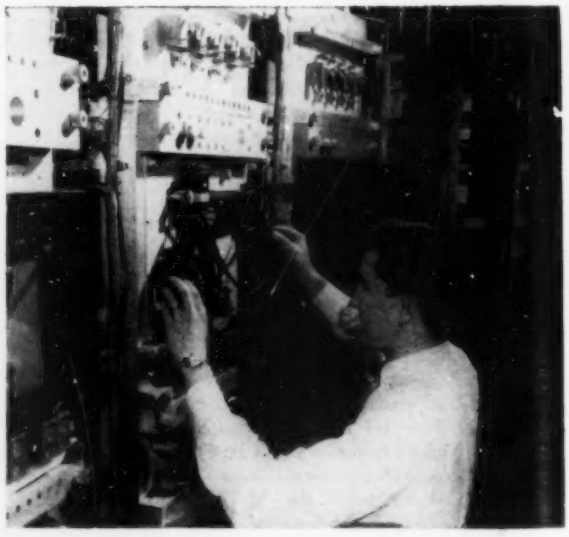
U. S. MILITARY AGENCIES are continuing to lean heavily on automatic computers to solve complex mathematical problems brought about by the trend to automatic weapons (Product Engineering, August, p 186). The two latest additions in the field are digital computers: RAYDAC (Raytheon Digital Automatic Computer) was built by the Raytheon Mfg. Co. for the U. S. Navy Bureau of Aeronautics to analyze guided missile flight problems; "Teleplotter" was developed by the Naval Ordnance Laboratory to augment present computer equipment.

RAYDAC is capable of being programmed to solve any problem in the field of numerical mathematics or of processing data in accordance with any logical system. It is composed of seven major units: clock, central control, arithmetic unit, internal memory, external memory, hunt unit, and operator's console. In addition as separate equipment there is a problem preparation unit and an output printer.

This computer is of the four-address type, using serial transmission of digits, serial-parallel acoustic mercury delay line internal storage, and having a basic pulse repetition rate of 3.77 megacycles per second. The machine operates in the binary system with a basic precision of thirty-one binary digits including the sign. The word length is thirty six digits; the remainder are used for checking.

The external memory consists of four tape handling mechanisms, each of which can store 700,000 characters in 3,150 blocks. Each block in the external memory has an address printed in binary code on the reverse side of the magnetic tape so that the computer can obtain access to stored information. As a result, for a computation, the machine has access to 2,800,000 stored decimal digits.

Information is stored in the internal memory in the



CLOSEUP OF EXTERNAL MEMORY as technician threads one of the four magnetic tape recorders capable of storing 700,000 decimal digits in 3,150 easily accessible blocks.

form of ultra-sonic pulses in mercury "delay-line" columns. The pulses represent actual numbers previously fed into the internal memory automatically and circulate within the confines of the delay lines 200,000 times per minute, until they are called out to be used as factors in a calculation. Despite the large storage capacity, the internal memory is about the size of an ordinary shoe box.

The Computer is self sequenced so that the end of one operation initiates the next. Operation times vary depending on the operation to be performed and for some operations, the operands. Computation of a typical problem proceeds at the rate of about 1,600 operations per second.

Specifically, RAYDAC can perform 1,900 additions, 1,900 subtractions, 1,100 divisions, or 1,400 multiplications per second.

One unusual feature of the computer is a built-in "check and double check" system. A check pulse indicating correct operation must be delivered to the sequencing circuits before computation can proceed. Transfers of words within the machine are checked by means of a transfer weighed count process and arithmetic operations are checked by means of identities operating on arithmetic weighed counts.

On the operator's console there is a directly connected printer for viewing intermediate results, as well as keyboards for manual entry of data and instructions. The operator can view any word located in any register or storage position in the computer.

Information is put into the computer on magnetic tapes that are prepared from paper tapes punched on a modified teletype machine. The output unit is a modified teletype printer with manual and automatic format controls to permit printing results direct from magnetic tapes.

While RAYDAC is a giant-size calculator (it's 44 ft long), original plans had it much bigger. The use of 5,000 miniature vacuum tubes and 18,000 germanium diodes permitted Raytheon to make the computer room-size instead of building-size. However, the miniature tubes require a cooling system that uses enough refrigerant to cool 50 home refrigerators.

Here's how guided missile designers will use this machine: When the guided missile is launched, ground radar stations will record its speed, altitude, and direction on high-speed recorders. Inside the missile, miniature transmitters will send out information on the speed, how fast it is using up its fuel, the temperature of the missile's engine, it's angle of ascent and descent and other data. All this information will be coded and fed into the computer.

Instantaneous solutions of flight problems will enable the designers to analyze the flight as it proceeds instead of waiting 20 to 30 days for manual calculations.

Raytheon spokesmen feel that RAYDAC has a bigger future than just analyzing guided missile problems. They visualize its use for such operations as predicting weather conditions days in advance to a high degree of accuracy, and performing tedious clerical operations of insurance companies, banks, tax bureaus, and business in general.

NOL Machine Plots Digital Solutions

Computing facilities at the Naval Ordnance Laboratory have been expanded by the addition of the "teleplotter," the first installation in the country that automatically plots digital solutions for many different kinds of problems. The machine automatically plots six distinct kinds of results as they are computed by other electronic calculators.

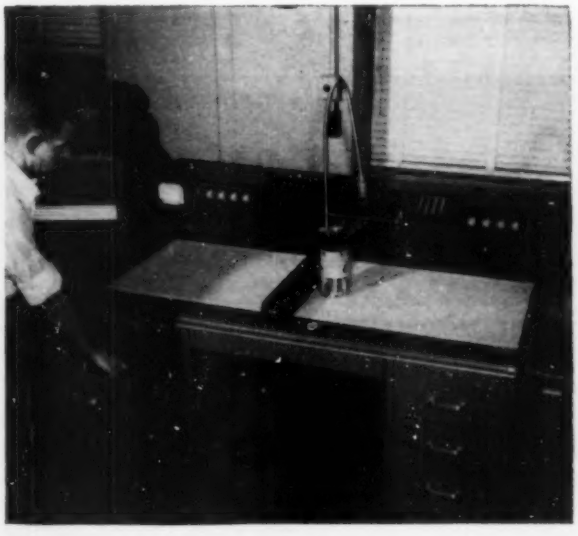
Built by the Telecomputing Corp., Burbank, Calif, the new machine is about the size of an ordinary office desk and has 600 vacuum tubes.

This is how the Navy scientists will fit the teleplotter into their present computing setup:

Data and instructions will be fed into the control unit of their present CPC calculators. The data will then go to the calculating unit where the operations will be performed. The results will be transmitted to the card output machine where they will be punched on cards or sent to the teleplotter where they are plotted. Scientists claim that the plotted data is much easier to interpret than that on printed cards or sheets.

One use NOL plans for their new machine is to plot trajectories of missiles to tell whether the missile will be stable and to compute the path of the yaw without actually firing the missile.

It also can be used to plot velocity and pressure waves resulting from the detonation of explosive charges, and plot pressure profiles. NOL claims that the new machine will reduce data interpretation time by a whopping 90 percent.



TELEPLOTTER developed by Naval Ordnance Laboratory plots digital solution to problems. About desk size, the newest computer contains 600 electronic tubes and cost about $15,000.

NOL COMPUTING CENTER. Data is fed into controlling unit of computer (front left), is transmitted to calculating machine (left rear), and then to teleplotter (right).

Processes: Photographic Imprint Saves Man-Hours

BELL AIRCRAFT CORP., BUFFALO, N. Y., has developed a method of printing numbers, letters, and symbols photographically on bare surfaces of steel, aluminum and plastic parts. Bell claims the new process provides a clearer and more uniform result as well as substantially reducing the time required to manually print the information with pen or stamp.

In this process a new developer and sensitizer (K&E #3053) made by Keuffel and Esser Company is used. K&E #3053 has three components: solution A for sensitizing, and solutions B and C for developing.

Here is how Bell prints information on channels and chassis:

Leroy drawings of the part to be imprinted are made on vellum. Information is positioned to allow clearance for grommets, tinning, bolts, and rivets.

The drawings are copied photographically and positives are made from the negatives. Each positive is placed on double-backed cellulose tape so that absolute contact with the emulsion is made. The tape is longer than the positive so that it can be easily aligned and removed.

Sensitizing solution is sprayed on the surface of the part. A coat of medium thickness is adequate as long as it completely covers the surface.

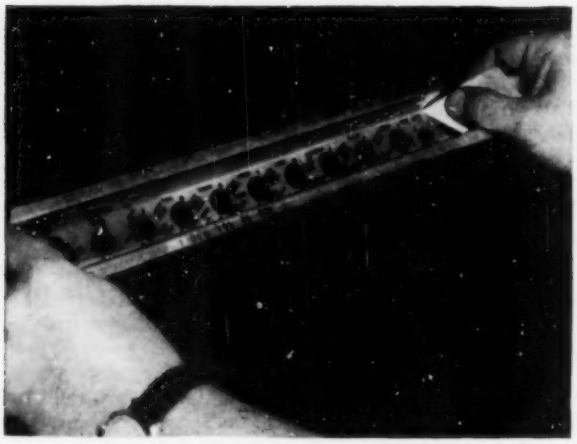
The emulsion is then dried by infra red lamps in five minutes, or in air for 20 minutes.

After the emulsion is dry, the positives are positioned on the part and applied with a slight pressure to make the cellulose tape stick.

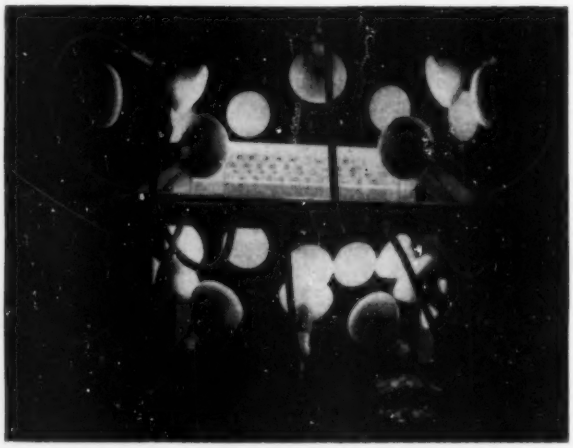
Imprinting is done when the emulsion is exposed to fluorescent tubes or photoflood lamps.

To develop the image, a mixture of solutions B and C applied on cotton is wiped across the exposed surface. While the surface is still wet, it must be handled carefully since pressurized air will remove the emulsion.

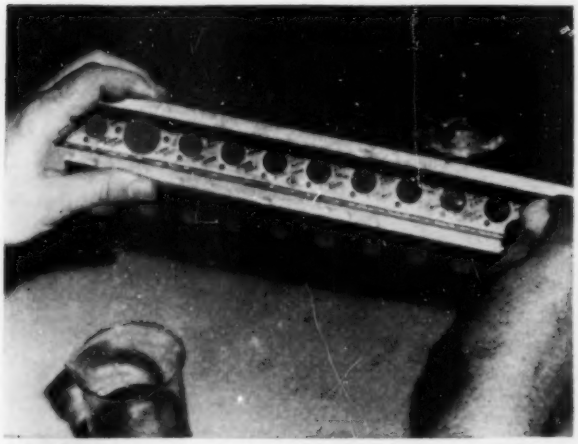
The dried image is permanently protected by spraying with a solution composed of equal parts of 3M-776 cement (made by the Minnesota Mining and Mfg. Co.) and M.E.K. (methol, ethyl, and ketone). This coating will protect the printing from chemicals usually found around a plant and will also serve as an insulator.



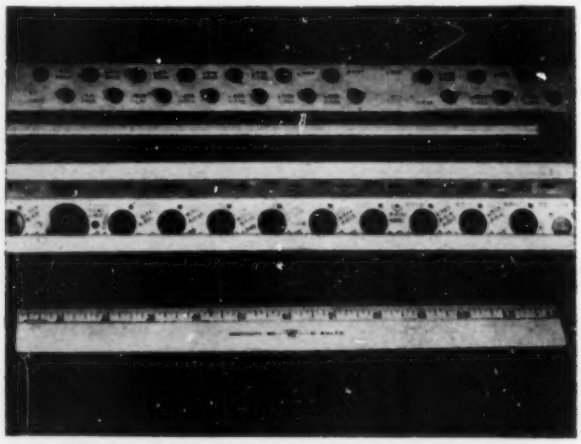
NEW PROCESS prints information on metal and plastic parts. Here positive print of information mounted on cellulose tape is positioned over sensitized surface of aluminum channel.



EXPOSURE by 24 photo-flood lights for ten minutes transfers information onto emulsion. The process will reproduce half tones, and can use incandescent, or fluorescent light.



DEVELOPING is done by wiping with a piece of absorbent cotton soaked in a mixture of K&E #3053 solutions B and C. Then part is rinsed in cold water and no darkroom facilities are required. Emulsion is an autopositive, unaffected by temperature.



FINISHED PART is protected with a spray. This channel had 122 five digit numbers printed on it at one time with the new process. Figures were laid out to miss the 85 holes in the channel. If necessary, methanol will erase the printing.

Steel Strikes Cost 20 Million Tons

WASHINGTON—The recent eight-week steel strike and the two stoppages in April cost industry 20,000,000 tons of steel, almost 20 percent of the anticipated output for 1952. In dollars of production and wages, the cost will run from one to four billion dollars.

As a result, the National Production Authority has shelved plans to decontrol steel. Now it is doubtful if steel will be plentiful until April of next year, and full decontrol cannot be expected before the summer of 1953.

Serious byproduct of the strike was the curtailment of iron ore shipments from the Great Lakes Region. This shortage will not be felt until mid-winter when the Great Lakes freeze up and stop shipments. Some steel people predict that the mills will have to cut down to less than 85 percent of capacity because of an ore shortage.

But despite production losses, NPA plans to boost self-authorization limits on carbon steel from 60 tons to 500; on alloy, from 16 tons to 90; and on nickel-bearing stainless steel from 500 lbs to 10,000. Such a regulation is now being drafted and will go into effect in January so that most small and medium-sized manufacturers will buy steel without CMP tickets.

$30,000 Design Awards

THE JAMES F. LINCOLN ARC WELDING FOUNDATION OF CLEVELAND, OHIO has announced a new competition for designers, engineers, and manufacturers of machinery of all types. The foundation will award 101 cash prizes totaling $30,000 for the best technical papers describing mechanical design and construction of any type of machine or machine component that is designed for arc welded steel fabrication.

Any person who has participated in the designing, planning, or manufacturing of machinery can compete for prizes in one of the 18 contest divisions. Each division has a first prize of $500, a second prize of $250, and a third prize of $150. And there will be 39 honorable mention awards of $100. In addition, a total of $9,900 will be awarded as grand prizes to the best 8 papers presented.

Complete rules may be obtained by writing to the Lincoln Foundation, Cleveland, Ohio. The contest closes July 27, 1953.

AIRBRASIVE UNIT was developed by the S. S. White Dental Mfg. Co. to use new gas-propelled abrasive cutting process. Operated on 110 v, 60 cycle a-c, the unit is supplied with right-angle nozzles for manual operation, and straight nozzles for production work where nozzle would be held in a fixture.

High Speed Abrasive Makes Accurate Cuts

USING A HIGH-VELOCITY STREAM of sharp-edged abrasive particles, the S. S. White Dental Mfg. Co., New York, N. Y. has developed a process for the precision cutting of hard-to-work materials. Traveling at a speed of 1,100 fpm, the particles pass through a sintered tungsten carbide nozzle with a diameter of 0.018 in. and impinge against the work surface.

While the abrasive cuts through hard and brittle surfaces rapidly, it has no effect on resilient or soft materials such as rubber cloths, and certain types of plastics. In addition it will not damage skin tissue if an operator accidentially places his hand in front of the stream.

Because of this selective cutting effect, the process has considerable promise for removing metallized films coated on relatively soft bases. It also can be used to drill thin sections of hard materials as well as cutting and etching hard and brittle substances.

S. S. White claims that there is no increase in temperature during cutting, and there is no vibration. As a result they recommend this technique for working on materials such as germanium whose physical and electrical properties might be affected by heat and shock.

Another advantage of the technique is that there is no direct contact of the tool with the work. This prevents dimensional variations caused by wear of the cutting tool or by surface irregularities in the work.

Normally, a specially processed aluminum oxide powder is used as the abrasive. For special applications that require a lighter abrasive, classified dolomite (a mixture of calcium and magnesium carbonates) can be used. However, standard commercial trades of abrasives are not suitable.

Any dry insert can be used to propell the abrasive, carbon dioxide is usually recommended.

GE to Supply UHF TV Station

THE GENERAL ELECTRIC COMPANY will supply the first high power, ultra-high-frequency television station in the United States to WHUM-TV in Reading, Pa. With an effective power of 261 kw, the station will be the most powerful in the world when it starts broadcasting early in 1953. 12 kw output of the transmitter will be multiplied twenty-five times by a special 1036 ft tower erected on top of a 1650 ft hill. This will make WHUM-TV powerful enough to cover a 60 mile radius with a fringe area beyond that.

The GE equipment will permit the telecasting of live talent studio shows, remote events, film and network programs on Channel 61 in the new UHF band.

Research: High Temperature Reduces Pure Nickel Tensile Strength

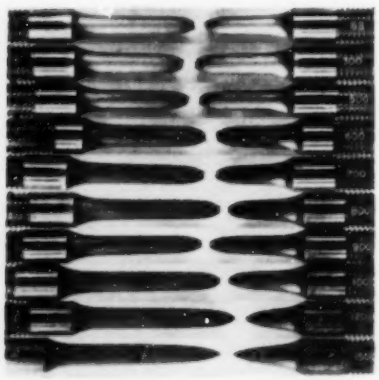
THE NATIONAL BUREAU OF STANDARDS' Thermal Metallurgy Section has completed an investigation into the effect of high temperature on 99.85 percent pure nickel. The study indicates that the yield and tensile strength, as well as the ductility at maximum load, are sharply decreased with a substantial increase of temperature.

While the study showed that elongation at complete fracture attains a minimum at about 500 F, irregularities appear in the usual trends of some of the tensile properties in the temperature ranges of 80 to 300 F and 500 to 700 F. In the lower range, the irregularities are apparently caused by strain aging; Curie point behavior seems to be responsible for the abnormal behavior in the higher range. Recovery and recrystallization are the predominant factors in ductility in the temperature range of 1,200 to 1,500 F.

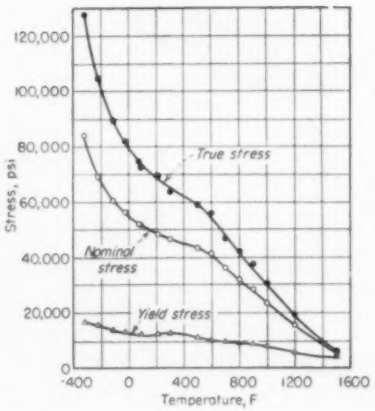
NBS made two series of tests. In the first, temperatures ranged from room temperature to 1,500 F. After the specimen was heated to the desired temperature, it was tested in a hydraulic machine that applied tension to produce extension at a controlled rate of about one percent per minute.

In the second series of tests, temperatures ranged from —320 to plus 212 F. Loading was controlled to produce a contraction of the smallest section of the specimen at a rate of approximately one percent reduction of area per minute.

In both series of tests, specimens were extended to the point of fracture so that the fracture could be examined metallographically.



FRACTURED SPECIMENS of pure nickel. Figures on right hand side of specimen indicate temperature at which test was conducted. Notice how increasing temperature affects the fracture.



EFFECT OF TEMPERATURE on yield strength (0.2 percent offset), nominal stress at maximum load, and true stress at maximum load. Loading was applied so that extension was one percent per minute.

This investigation is a continuation of previous NBS studies on high purity copper and copper-nickel alloys (reported in PRODUCT ENGINEERING, Feb. 1952, p. 201). Since both materials are available in highly purified form and their alloys have relatively high strength at elevated temperatures, such data is needed for industrial and military applications.

Strain History Determines Low Temperature Properties Of Ingot Iron

WASHINGTON—Ductility at low temperatures of ingot iron depends not only on the instantaneous values of strain and the temperature, but also on the previous strain-temperature history of the specimen. This is the conclusion reached by metallurgists at the National Bureau of Standards as a result of an investigation into the causes of metal deformation at low temperature.

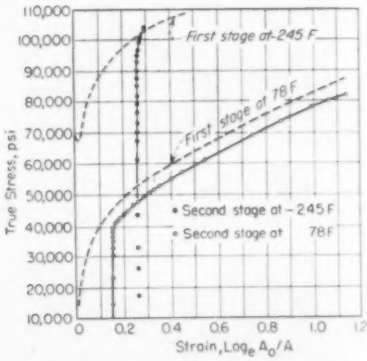
For ingot iron specimens extended in tension in the temperature range from —250 to +212 F, NBS scientists found that total work hardening, the increase in true stress with true strain, is the result of two processes: strain hardening and strain aging. The former is caused by crystal deformation and increases as the testing temperature is lowered; while the latter is associated with the precipitation of an element from solid solution and increases, within limits, with an increase in temperature. Below —180 F, the work hardening of ingot iron during deformation in tension is primarily strain hardening. Above this temperature, the strain aging during deformation increases sufficiently to become the dominating factor.

Previously, metallurgists have felt that strain aging was insignificant at sub zero temperatures. But analysis of the relative proportions of strain aging and strain hardening indicates that aging has a pronounced effect at temperatures as low as —180 F.

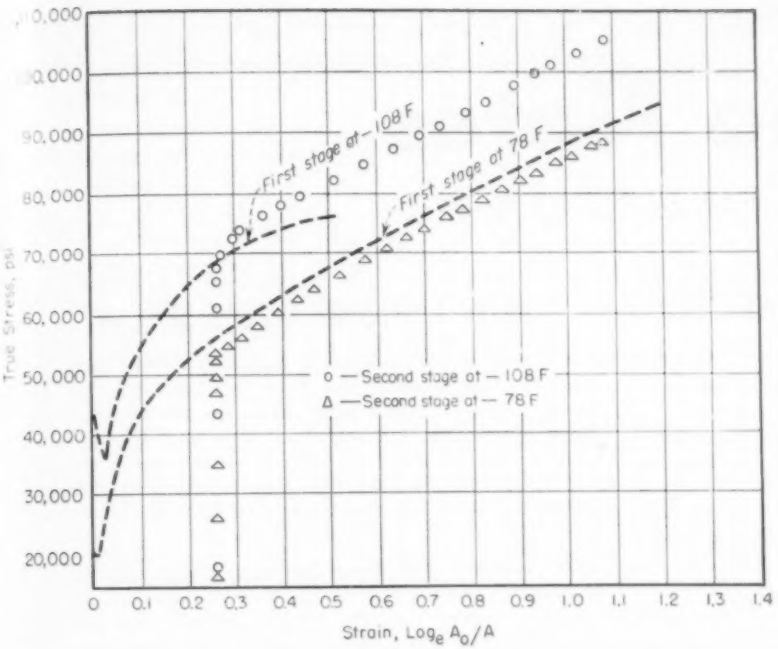
The investigators also found that rheotropic brittleness of ingot iron depends on the initial condition of the material. This is the part of low-temperature brittleness that can be removed by cold working at temperatures above the transition point from ductile to brittle behavior. How cold working a specimen by extension in tension at room temperatures affects brittleness depends on how the specimen was processed and heat treated.

Cold working at room temperature removes some of the brittleness in hot-rolled or normalized specimens, but it increases the low temperature brittleness of annealed ingot iron.

In this study, ingot iron specimens were classified into five groups according to their processing and heat treating: (1) annealed, (2) hot-rolled, (3) quenched and tempered, (4) normalized, and (5) cold-drawn. These were machined into cylindrical tensile specimens and extended in tension to specified strain values in a pendulus type hydraulic testing machine. During



ANNEALED INGOT IRON true stress-strain data. Closed circles represent data obtained during extension at —245 F after a first stage extension at 78 F; open circles represent data obtained during extension at 78 F after a first stage extension at —245 F. Note that cold working at 78 F caused the annealed ingot iron to become brittle when tested at —245 F.



NORMALIZED INGOT IRON true stress-strain data. Circles represent data obtained during extension at —108 F after a first stage extension at 78 F; triangles represent data obtained during extension at 78 F after a first stage extension at —108 F. Relative position of second stage data with first stage indicates pronounced effect of strain aging during deformation at 78 F. Cold working of specimen during first stage extension at 78 F greatly decreased its brittleness and increased its ductility during second stage extension at —108 F.

tests, liquid nitrogen baths maintained the desired temperature.

The specimens were extended at selected temperatures ranging from —250 to +212 F. Above a 30 minute interval, they were re-extended to fracture, at a different temperature within the same range. Simultaneous load and diameter measurements provided data to plot true stress-strain curves.

Deviation of the true stress-strain curve for the second stage of the test from the true stress-strain curve for the first stage (at the same temperature as that used in the second stage) gave a measure of the effect of the strain-temperature history during the first stage of the test.

Cold working at room temperature increases low temperature ductility of quenched and tempered iron, but has little effect on cold-drawn specimens.

Patent Office Cuts Application Backlog

WASHINGTON—In August the U. S. Patent Office reported that the backlog of patent applications was the lowest in six years. As of June 30th, there were 98,138 applications waiting the action of examiners, compared to over 200,000 just three years ago.

John A. Marzall, Commissioner of Patents, attributes the improvement to added efficiency of operation as the result of instituting reforms recommended by an outside management consultant. But the better showing hasn't slowed the criticism aimed at the office by inventors. Since it still takes anywhere from one to 10 years to get a patent, inventors charge that the office doesn't help them enough and may be stifling American ingenuity by discouraging the filing of patents.

Since the start of World War II, Patent Office operation has been fairly well muddled. While the workload dropped off during hostilities, the office was only barely able to hold its own because of a turnover in personnel. After V-J day, the office was swamped with applications resulting from wartime technological developments. In 1946, over 92,000 applications were filed, 40,000 more than in 1942.

Patent Office employees were in no position to handle this deluge. Part of the examining division had been moved to Richmond, Va., during the war to make room in Washington for war-born agencies. Located in an old tobacco warehouse eight feet below street level, examiners watched valuable papers deteriorate from railroad smoke and grime in their poorly ventilated offices.

It was not until 1947 that the office was brought together again in the Commerce Department building. But by this time the backlog had gotten completely out of control. In June 1948, it reached an all time high of 244,000 applications.

With no improvement in sight, the Patent Office called in a management consultant to survey its procedure. As a result, the office hired 100 new examiners and improved their housekeeping and filing. By June 1949, the backlog had been cut to 241,000, despite an increase of 100 percent in monthly patent applications.

Marzall's administration (he took over in 1950) has made an excellent showing, despite the loss to private practice of many experienced examiners.

He said: "Improved administrative practice enabled us to grant 46,531 patents last year and to dispose of 18,693 more than we received. While the total number of patents granted was less than the 50,250 granted in fiscal 1951, it exceeds the totals for any year before that since 1942."

Marzall noted that developments as a result of the mobilization effort have not yet started to swell Patent Office totals. Last year 64,992 applications were filed with the office, 3,116 below the previous year.

And despite increased military security, there has been no increase in new inventions that cannot be patented because of security classifications.

Classified inventions are processed all the way except for the last step, the actual granting of the patent. At this stage, they are placed in a "cold storage box" where military agencies and the Atomic Energy Commission get a chance to see them. To protect the inventor, everyone who sees the details must sign a certificate before he can view it to establish a record of who has seen the invention.

In addition to this protection, the inventor has a two-fold claim against the government: for using the patent (if the government actually does); and by reason of the patent grant being held up. The current extension of the law governing the sequestering of "secret" inventions guarantees this. But to date, no one has exercised this right by suing the government for damages for that reason.

DOW CORNING

Silicone Notes

ON LUBRICATION

REFERENCE NO. SL-53

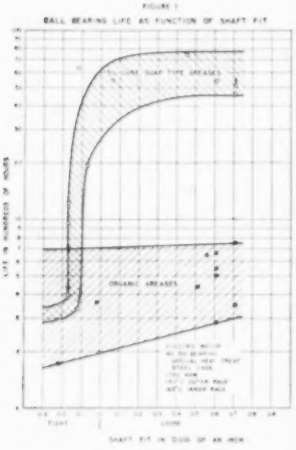
FILE SILICONE LUBRICANTS

Make sure you have basic data sheets BG-2, 5501b, 7102. If misplaced write Dept. R-21

DOW CORNING CORPORATION
Midland, Michigan

DOW CORNING 44 SILICONE GREASE

In electric motors which may operate hot, the mechanical fit-up of the bearing assembly has a critical effect on the life expectancy of silicone grease. This was proved by life-testing various greases in the bearings of totally enclosed non-ventilated induction motors operating at high temperatures. The relation between shaft-fit and life in hours is shown in Figure 1.



In the TENV induction motors used to test bearing life at 150°C., these curves indicate that the life of Dow Corning 44 lubricated bearings with a shaft-fit of 0.2 mils loose is about 15 times the life of identical bearings with a shaft-fit of 0.2 mils tight.

These data show the importance of mechanical fit-up. A tight shaft-fit, for example, may take up most of the radial clearance in the bearing. Where the inner race operates at a higher temperature than the outer race, unequal thermal expansion may put the balls under compression. Any combination of mechanical fits which produces radial clearances inadequate at operating temperatures, or poor bearing alignment, will subject the grease to extreme pressures and result in unsatisfactory bearing life.

The subject of Design Considerations for Optimum Performance of Silicone Greases in Ball Bearings is more fully developed in a paper recently read before the ASLE. Write for a copy.

DOW CORNING VALVE SEAL A

With a solidification point below —40°F. and no true melting point, Dow Corning Valve Seal A is unique among valve lubricants for its stability at both high and low temperatures and for its resistance to oxidation. It is generally inert chemically and physiologically; shows excellent resistance to hot water and to a wide variety of chemicals and gases.

The usefulness of Dow Corning Valve Seal A in chemical services too severe for conventional lubricants is indicated by tables recently published in a new data sheet describing its performance in valves handling more than 120 different chemicals and gases. Here's a representative sample taken from actual field service experience:

Reagent	Temperature, °F.	Rating
Brine (caustic)	Hot	Good
Calcium chloride (molten), 100%	327	Good
Sodium hydroxide, 60%	300	Fair
Sulfuric acid, 98%	77	Good
Lubricating oils	----	Good
Chlorinated phenols	Hot	Good
Slurry of aluminum chloride, benzoyl chloride and paraphenyl phenol	347	Good
Slurry of potassium dichromate, sodium chloride and sodium sulphate	265	Good
Acetylene	----	Good
Ammonia (liquid)	----	Good
Hydrocarbon gas	—120 to 500	Good

There are, of course, too many variables to permit specific recommendations. The tables from which these examples were taken do serve, however, to establish the fact that Dow Corning Valve Seal A is used successfully in many services where the life and reliability of valves is severely limited by failure of conventional lubricants.

For example: In the valves of large turbines, an electrical manufacturer recommends the use of Valve Seal A under pressures as high as 400 psi and temperatures ranging up to 750°F.

WRITE TODAY for more information on Dow Corning Valve Seal A. Please address Department R-21 and ask for data sheet No. VSA-1.

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Nomograph to Simplify Gear Tooth Calculations

W. T. WINTER
Western Gear Works

WHEN DESIGNING GEARS, it is often necessary to calculate the difference between the circular tooth and chordal tooth thicknesses as well as the addendum correction (see Fig. 1). The

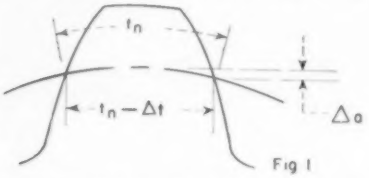


Fig 1

nomographs on the following pages yield these data without resorting to awkward derivations. They are not, however, based on exact solutions and some consideration of the errors introduced may be necessary.

The charts are based on equations derived from Fig. 2. If D is the dia,

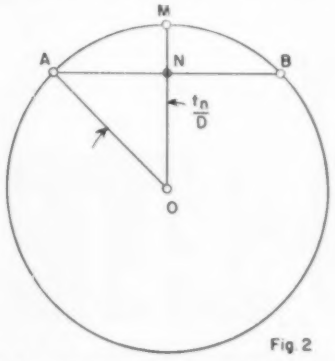


Fig 2

$OA = D/2$ and the arc $AMB = t_n$. Then $\Delta t = AMB - ANB$. The addendum correction, Δa, is equal to OM minus ON.

Thus

$$\Delta t = t_n - D \sin \frac{t_n}{D}$$

and

$$\Delta a = D/2 - D/2 \cos t_n/D$$

Expanding the sine and cosine functions into series and using only the first two terms of each series yields the following equations from which the nomographs were developed.

$$\Delta t = \frac{t_n^3}{6D^2} \quad (1)$$

$$\Delta a = \frac{t_n^2}{4D} \quad (2)$$

The magnitude of error in Eq (1) is less than the value of the first of the omitted terms of the expansion, namely, $D \frac{(t_n^4)}{D^5 5!}$ This error will be largest for values of t_n and D approaching those, as an extreme case, of a 7 tooth gear of standard tooth proportions and of $1\frac{1}{2}$ diametral pitch. Such a combination introduces an error less than 0.0002 in. The numerical magnitude of error in Eq (2) is less than $\frac{D}{2} \frac{(t_n^4)}{D^4 4!}$ which introduces an error less than 0.00025 in. under the same combination of values of t_n and D. Since this error is inversely proportional to the product of diametral pitch and the cube of the number of teeth, it diminishes rapidly as they increase, becoming only 0.00009 under the combination of 2 diametral pitch and 9 teeth.

To include helical gears as well as spur gears in the foregoing analysis, it is necessary to consider the differences under discussion in the plane normal to the tooth surface. The pitch cylinder intersects the normal plane producing an ellipse whose minor axis can be considered as terminating at the center of the tooth. Determining the radius of curvature at this point and expressing it as an equivalent spur pitch diameter discloses that it has the following relationship with the transverse pitch diameter of the helical gear:

Let

D = equivalent spur pitch diameter
D' = pitch diameter of helical gear in the transverse plane
ψ = helix angle

Then

$$D = \frac{D'}{\cos^2 \psi} \quad (3)$$

Substituting this value in Eqs (1) and (2):

$$\Delta t = \frac{t_n^3}{6\left(\frac{D}{\cos^2 \psi}\right)^2} \quad (4)$$

$$\Delta a = \frac{t_n^2}{4\, D/\cos^2 \psi}$$

Eqs (3) and (4) then represent the thickness and addendum corrections for helical gears.

Since the circle whose radius of curvature was determined by Eq (3) does not exactly fit the ellipse throughout the arc of the tooth, an error is introduced. By analytical geometry it can be shown, however, that this error is so small as to be completely ignored in most cases. It is only 0.00006 for Δa and less than that for Δt for values of t_n and D corresponding to those of a 7 tooth gear of $1\frac{1}{2}$ diametral pitch.

Spur Gear Example:

Given: Pitch Dia = 1.0
Diametral Pitch = 8.0

Solution:

Line I shows
Δt = 0.00125 in.
Δa = 0.0096 in.

Helical Gear Example:

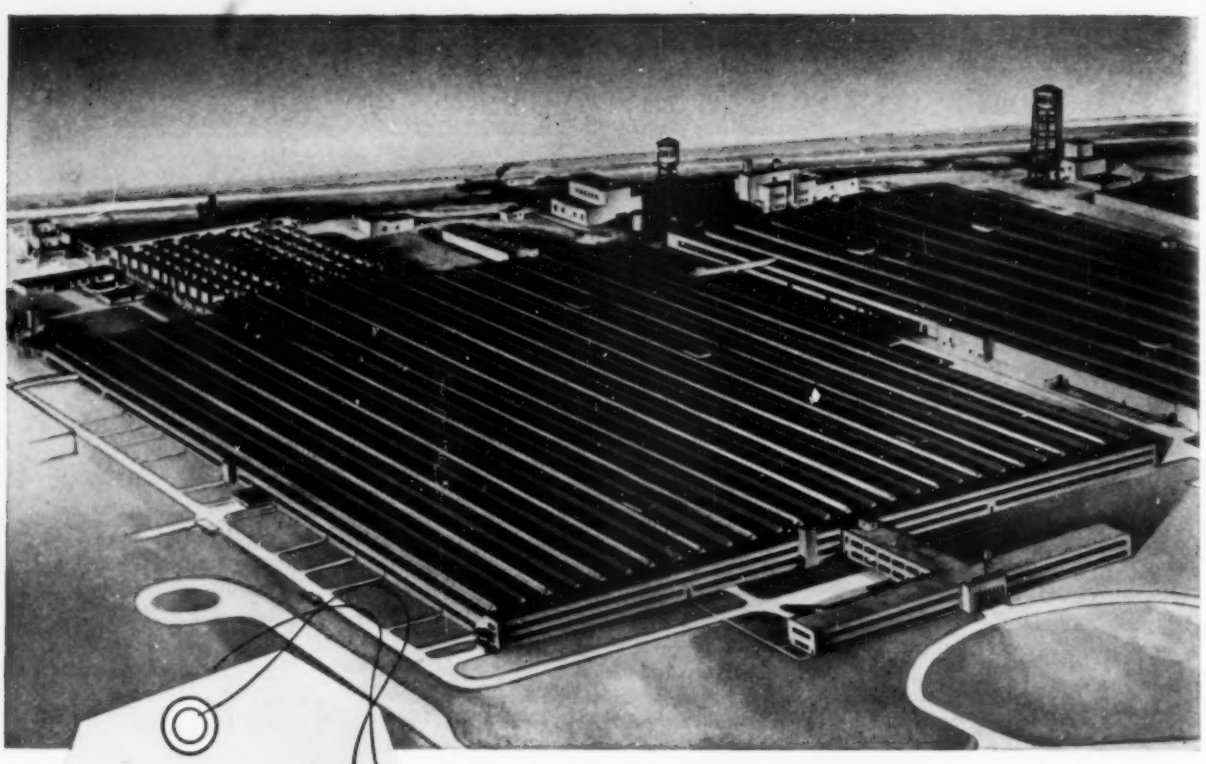
Given: Transverse Pitch Dia = 1.0
ψ = 30 deg.
Normal diametral pitch = 10.0

Solution:

Draw line II From D' = 10.0 to ψ = 30 deg.
Draw line III from intersection of line II with D scale to appropriate value of P_{nd}.
From line III
Δt = 0.00035 in.
Δa = 0.0046 in.

Chart II is identical to Chart I except that it is constructed for gears with larger dimensions.

(continued on page 207)



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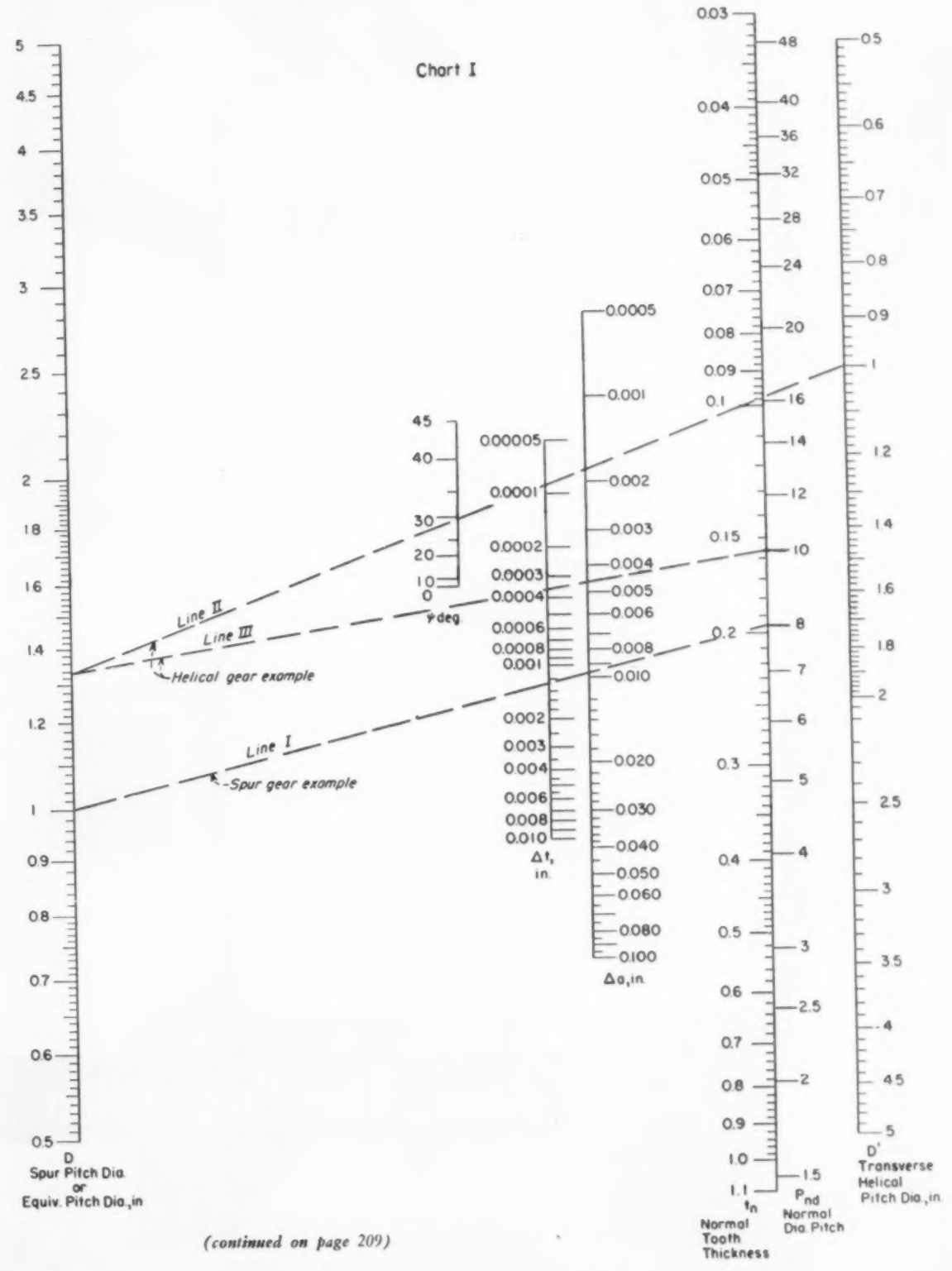
Nomograph to Simplify Gear Tooth Calculations (continued)



(continued on page 209)

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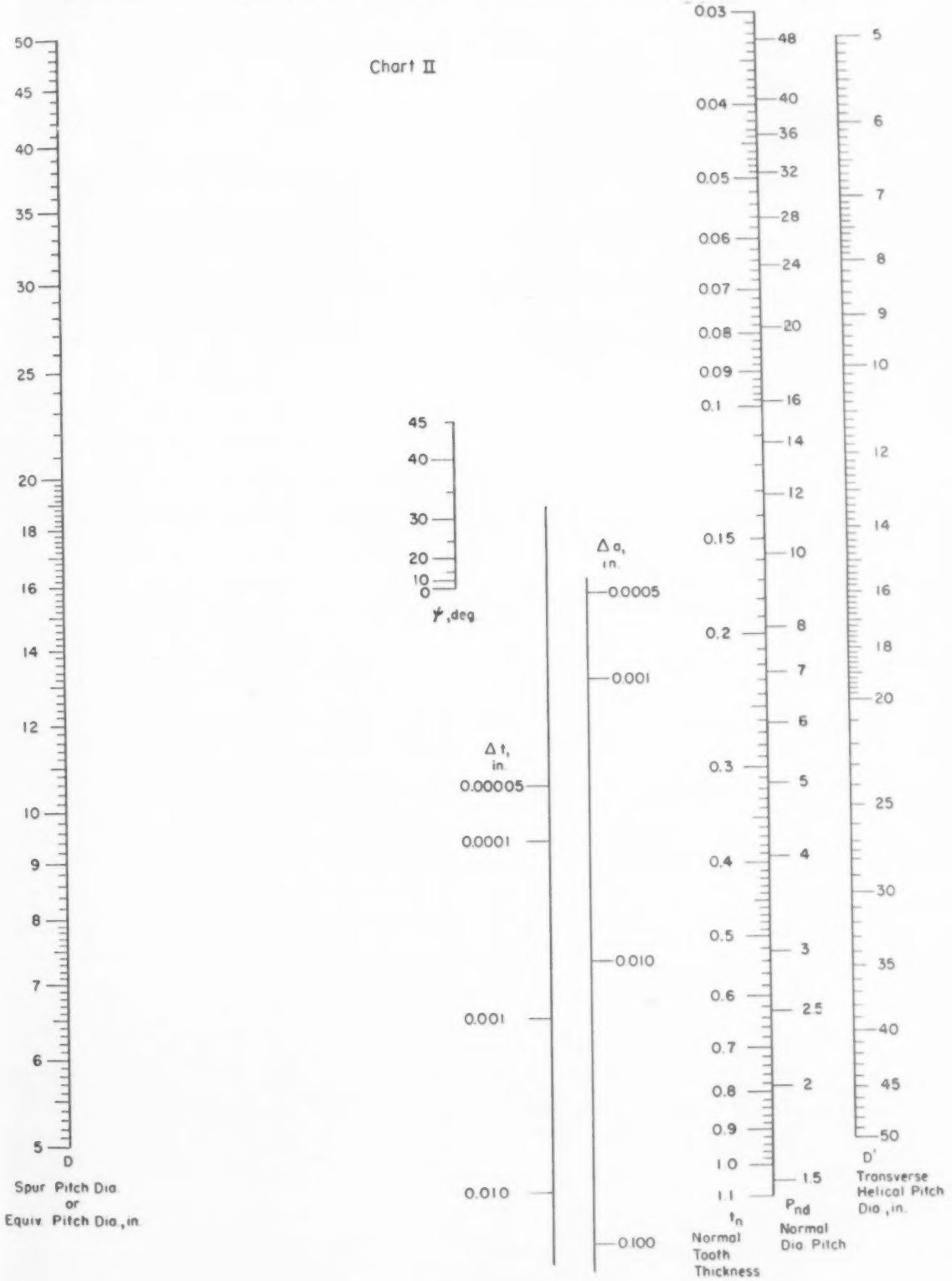
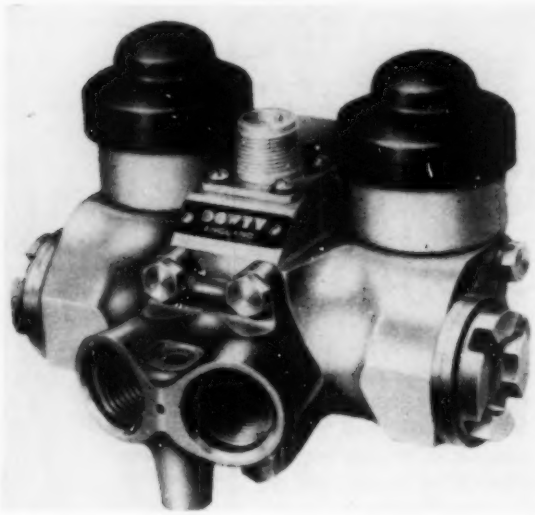
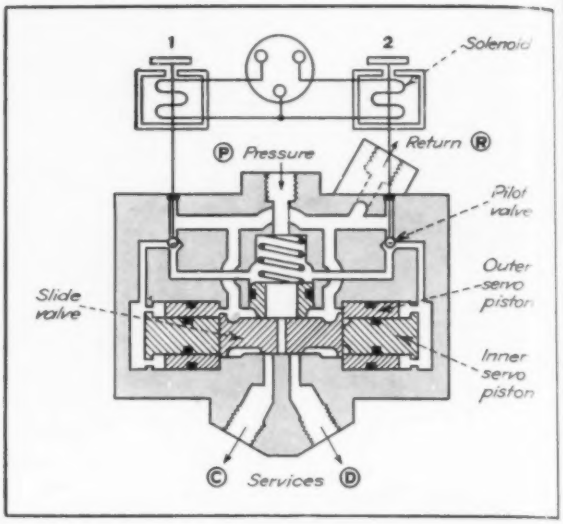
Nomograph to Simplify Gear Tooth Calculations (continued)







High Pressure Electro-Hydraulic Selector Valve

A recent addition to a line of electro-hydraulic equipment is the new Hydel selector valve for the selective control of hydraulic circuits. Basically, it consists of a hydraulic valve electrically operated through twin solenoids. These solenoids are controlled by a push-button or lever-switch. This form of electrical remote control simplifies the overall hydraulic system by eliminating much of the plumbing between the pilot's control and the actuating jack.

The view at left shows the type 4600-Y providing a four-way, three-position selection with blind neutral. Other three-way twin solenoid types, with or without a neutral position, or with the flow to the selected service either open or closed after de-energizing, and single solenoid two-way valves are also available.

Considering the four-way, three-selection (blind neutral) type 4600-Y in the valve series, the mechanism of operation can be followed by reference to the diagram at right. In a hydraulic circuit, the valve unit is supplied with fluid under pressure from the pump at point (P) and connected to the jack (or similar actuator) at points (C) and (D). The return line connection to the reservoir is made at point (R). With both solenoids de-energized, fluid pressure in the valve is contained within the housing of the spring loaded piston and the cylinders of the servo pistons. Equal pressure on the composite servo pistons holds them against stops at the inner ends of the cylinders. In this position it will be noted that they centralize the slide-valve in the neutral or closed position, both service ports (C) and (D) being blocked off.

The central port of the slide is sealed against a pressure tight face between the service ports (C) and (D). Pressure equilibrium is maintained in the valve by the pilot valves pressing on their upper seats as shown in the illustration. These pilot valves are controlled by the solenoids (1) and (2). When solenoid (1) is energized, it forces the valve off its upper seat on to the lower one, cutting off the pressure supply to the related servo cylinder, and causing the contained pressure to fall. In the other cylinder, the small servo piston moves inward, and pushes the central port of the slide-valve into position over the outlet connection (C). Pump pressure and flow are then lined up with the corresponding inlet connection on the actuator. The oilway on the right-hand of the slide-valve now located over the open port (D), permits free flow of oil to the return pipe-line (R).

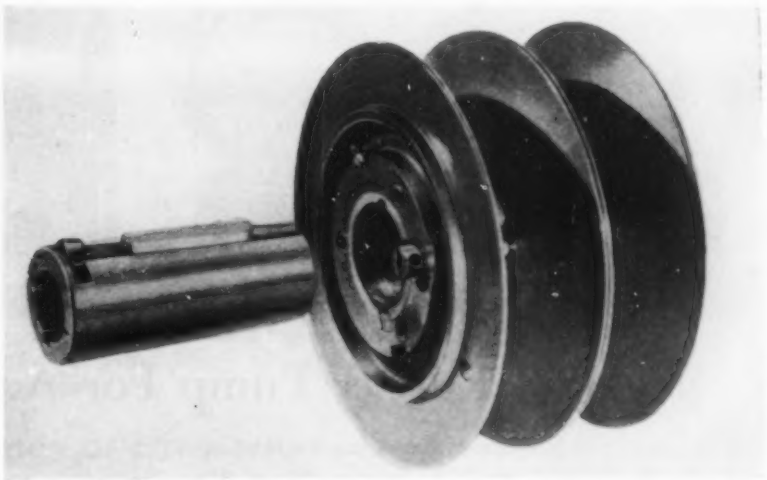
These conditions are maintained until the solenoid is de-energized and pressure equilibrium restored. Operation of the right-hand solenoid (2) causes the same action on the opposite valve and piston, with the effect of directing the pressure flow through port (D) and return to the reservoir through port (C). The sequence of events is rapid; with the selection of either service from neutral being completed in 0.12 sec, while the return to neutral is performed in 0.03 second.

The solenoids are continuously rated for voltages between 28.5 and 22, with a test voltage of 16 at a temperature of 20 C; they are detachable and are suitable for continuous operation in all climatic conditions. In the event of electrical supply failure, pressure in the selected circuit is maintained by the automatic movement of the slide to the central (closed) position.

Both single and twin solenoid types of the valve are designed for hydraulic systems with operating pressures up to 4,000 psi at any temperature between 70 C above and 54 C below zero. The normal flow capacity is 20 gal/minute. The single solenoid type weighs 1.9 lb and the twin solenoid, 2.5 pounds.

Dowty Corp., 25 Beaver St., New York 4, N. Y.

Wide Range Variable Pitch Sheaves



For use with a stationary-control, wide range, vari-pitch sheave with Q or R section belts, a new type of "magic-grip" bushing makes possible a quick and easy installation of the sheave and permits mounting it on the shaft so that the adjusting control mechanism is either toward the motor bearing or away from it.

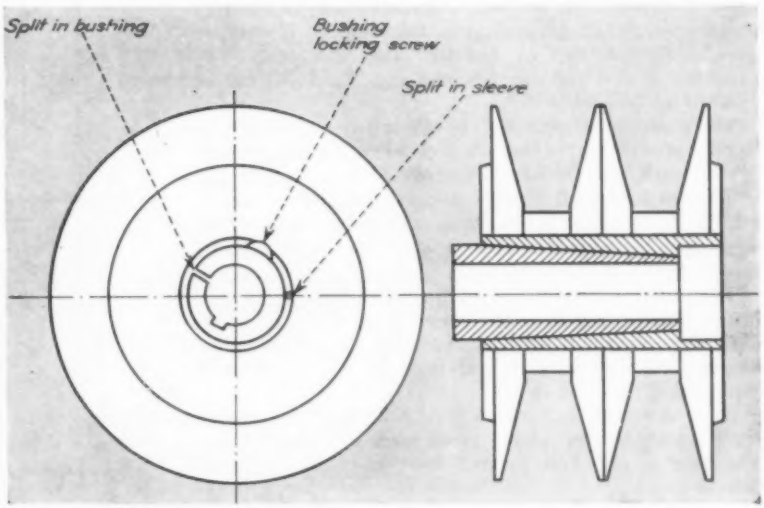
This bushing incorporates the use of a tapered sleeve clamp action mechanism which consists of two split tapered sleeves, one within the other. Drawing them together with the locking screw produces a double action result. The bushing sleeve is contracted on the motor shaft, and the sheave sleeve is expanded against the disks simultaneously, effectively locking the entire mechanism together.

The wide-range vari-pitch stationary control sheave makes use of the vari-pitch sheave principle of mechanically moving angular faced disks nearer together, or farther apart, thus changing the pitch diameter of the sheave.

The wide-range stationary control sheave has a positively actuated mechanism which maintains true pitch diameters. It consists of two sets of movable disks mounted on a main sleeve. These disks are bolted together to form separate assemblies, and are adjusted manually with a rod which turns an adjusting screw. This screw is so constructed that it moves both disks of each groove at the same time, maintaining alignment of the belts. The disks are made of special grade alloy iron and are heat treated.

The wide-range vari-pitch sheaves have been developed for use with standard motors from 1½ to 30 hp with motor speeds from 1,800 to 900 rpm. The standardized shaft diameters and projections of NEMA frame motors will require a definite size sheave for each motor size.

Allis-Chalmers Mfg. Co., General Machinery Div., Milwaukee, Wis.



Motor Hp	Motor Speeds					
	1750 rpm		1160 rpm		865 rpm	
	Pitch Dia.	Belts	Pitch Dia.	Belts	Pitch Dia.	Belts
1½	4.0 to 7.5	1Q	3.5 to 7.0	1Q	3.5 to 7.0	2Q
2	4.0 to 7.5	1Q	3.5 to 7.0	2Q	3.5 to 7.0	2Q
3	4.0 to 7.5	2Q	3.5 to 7.0	2Q	5.0 to 8.5	2Q
5	4.0 to 7.5	2Q	5.0 to 8.5	2Q	5.25 to 10.0	2R
7½	5.0 to 8.5	2Q	5.25 to 10.0	2R	5.25 to 10.0	2R
10	5.25 to 10.0	2R	5.25 to 10.0	2R	6.25 to 11.0	2R
15	5.25 to 10.0	2R	6.25 to 11.0	2R	6.25 to 11.0	3R
20	6.25 to 11.0	2R	6.25 to 11.0	3R	7.25 to 12.0	3R
25	6.25 to 11.0	3R	7.25 to 12.0	3R	.....	.....
30	7.25 to 12.0	3R	.....	.....	.....	.....

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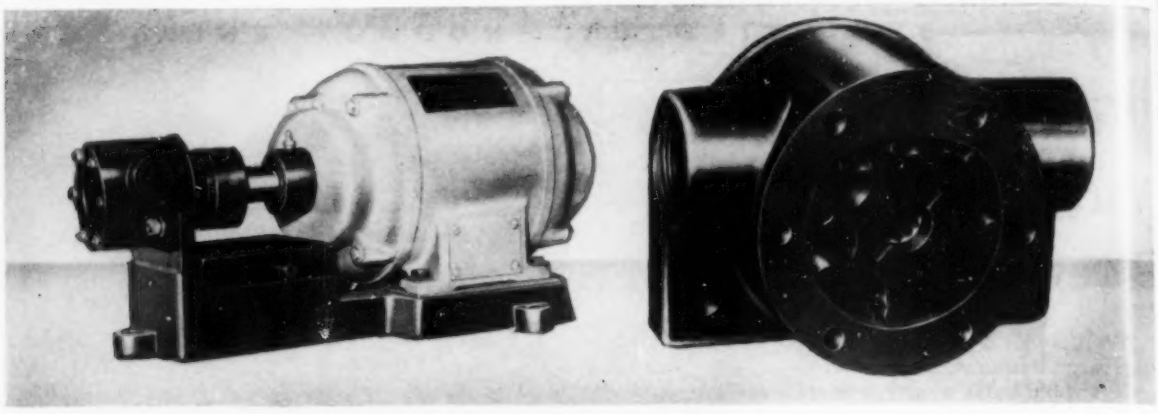


Hard Rubber Pump For Acids, Alkalies

Now available in hard rubber construction for handling acids, alkalies, and other corrosives, a small, neoprene impeller pump will deliver 15 gpm at 22 ft. head, or 5 gpm at 72 ft. head. The maximum capacities are 95 ft. head or 16 gpm. It pumps viscous or thin liquids, is resistant to alkalies, solutions of metallic salts, inorganic acids, hydrochloric acid any strength, and any liquid that can be handled by neoprene.

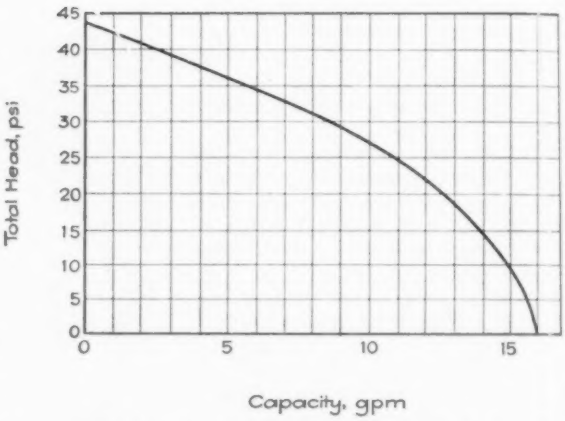
The pump is self-priming. It will start instantly against suction lifts of 6 ft without a foot valve. When primed, it will handle suction lifts as high as 14 feet.

The self-lubricated flexible neoprene impeller is said to outlast conventional metal rotors and gears, and is self compensating for wear. The impeller can be replaced by simply removing the cover plate.

The pump is threaded for ¾ in. standard pipe threads. It can operate equally well in either direction, reversing flow. The motor is ½ hp, 1,140 rpm, polyphase, close-coupled with the impeller, and mounted directly over the motor shaft.

Corrosion-resistant hard rubber is used in the molded pump casing, cover plate, gland parts, and drip pan. The base is cast iron painted with acid-resistant paint.

PUMP CAPACITY CHART



Mounting bolts and studs are stainless steel. Shaft, impeller insert and key are made of Hastelloy C.

American Hard Rubber Co., 93 Worth St., New York 13, N.Y.

Oil-Tight Pushbutton Units

Oil-tight pushbutton units for machine tool applications, designed completely on the building-block principle, incorporate self-a-line contacts and removable color rings for pushbutton identification. This building-block construction permits increased flexibility of application because the basic units can be arranged in various combinations to meet all special as well as standard requirements. The manufacturers claim that two operators, five color rings, and two contact blocks can be arranged in any of twenty different combinations.

The self-a-line double break contacts are placed at an angle so they close with a rolling action. The operating lever strikes a curved surface on the movable contact, retaining alignment and adjusting evenly to wear. The contacts then always break simultaneously. The only basic form of contact block used in the new units is a single-pole, double-throw type made of melamine for maximum arc resistance. Double-pole, double-throw combinations are made by mounting two of these units on the same base.

As the contact blocks are located on the back, the manufacturers claim that as much as 60 extra feet of connection wire can be eliminated from the standard 9-unit station with this assembly.

Units come in 1, 2, 3, 4, 6 and 9 button stations, with contacts rated at 115, 230, 460, and 575 volts. Depth of unit enclosures is $3\frac{7}{32}$ in., and a standard pushbutton extends ½ in. beyond the case.

General Electric Co., 1 River Rd., Schenectady 5, N. Y.

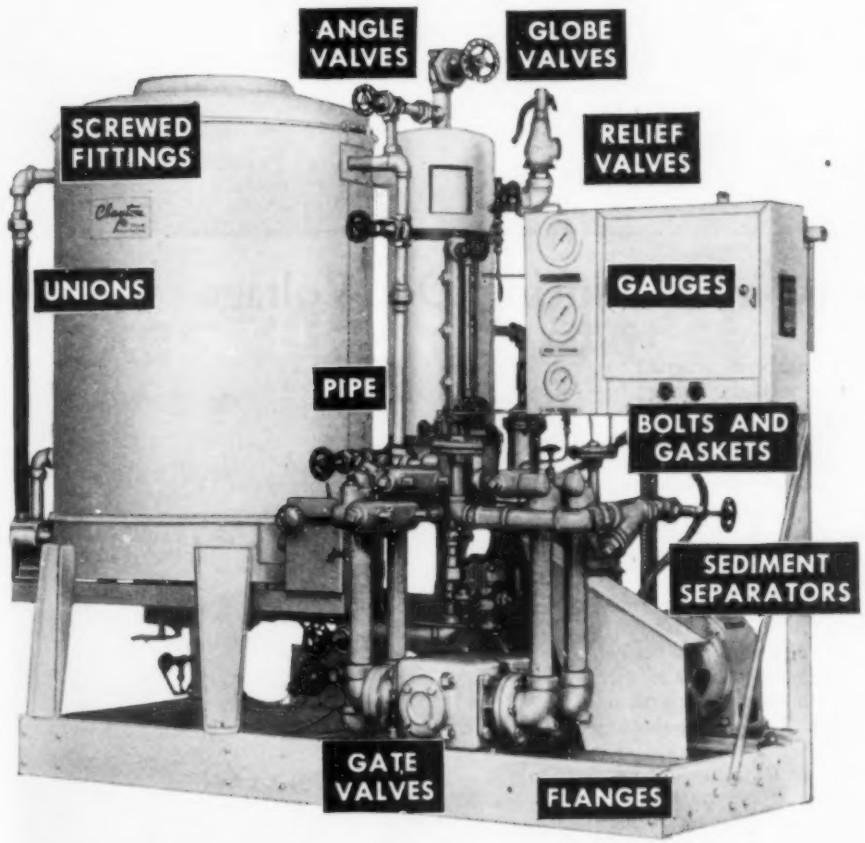
CONTINUED ON PAGE 214

Key to better piping design . . . your easy-to-use CRANE Catalog

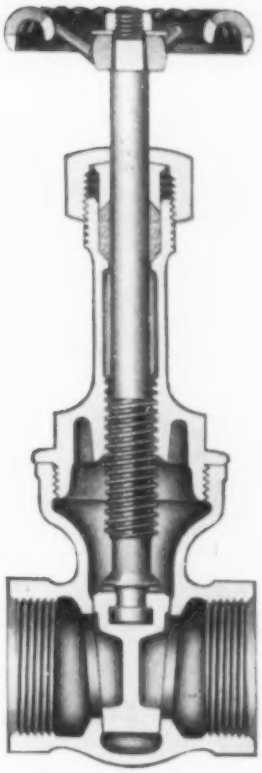
You can design better piping into any product . . . faster . . . when you specify from your Crane Catalog. Here, between two covers, you'll find the world's most complete assortment of quality piping materials—carefully arranged for convenient selection. And for every piping item there's a full listing of recommended services; complete design, material, and construction details; plus helpful, easy-to-use pressure and temperature rating tables. In addition, your Crane Catalog answers general engineering questions connected with designing efficient piping systems.

Specifying Crane gives your product added value, too. Now that replacements are harder to get, your customers realize more than ever the advantages of dependable, longer-lasting Crane Quality equipment on the machinery they buy.

FOR A BIGGER SELECTION OF BETTER PIPING . . . CHECK THE BROAD CRANE LINE



Steam Generator by Clayton Manufacturing Company, El Monte, California



FOR RUGGED, DEPENDABLE service on steam, water, oil and gas lines—Crane recommends 150-Pound Brass Gate Valves with accurately guided solid wedge disc. Tight stem seal assured by high quality stuffing box packing and gland; can be repacked under pressure. Rising or Non-Rising Stem; screwed or flanged ends. Sizes: ¼ to 3-inch. See your No. 49 Crane Catalog, page 17.

CRANE CO.

General Offices:
836 S. Michigan Ave., Chicago 5, Ill.
Branches and Wholesalers Serving All Industrial Areas

VALVES • FITTINGS • PIPE • PLUMBING • HEATING

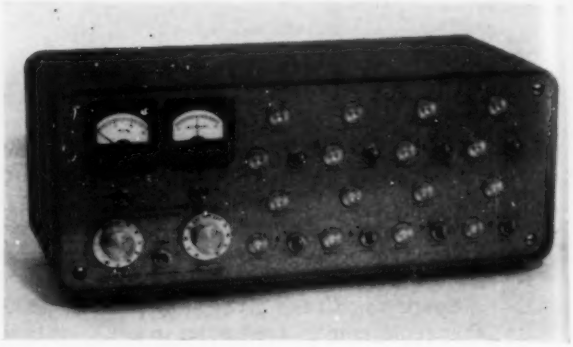
New Bridge Balance Simplifies Direct Recording

A completely new 8-channel bridge balance, type 8-108, has been added to a line of recording instruments, and may be used for direct recording of the output of a wide variety of strain gages and strain gage type pickups without the use of amplifiers. Used with this company's 5-114 or 5-116 recording oscillographs, the new 8-108 is easy to operate at a resultant high degree of accuracy.

Up to eight 120- to 350-ohm strain-gage bridges or strain-gage-type pickups, comprising four active arms, may be connected to the instrument. If fewer active arms are used, dummy gages can be added externally. Voltage across each bridge can be adjusted individually and continuously from the level of the supply voltage, 28.5 d-c maximum, down to a minimum of 2.0 v on a 350-ohm, four-arm bridge and 1.1 v on a 120-ohm, four-arm bridge. Each channel has its own front-panel voltage control, and the channel selector switch connects any channel to the voltmeter circuit. Adjusting voltage individually on each bridge permits pickups of different resistance value to be used simultaneously, while maintaining on each, optimum wattage dissipation, and minimizing drift problems.

The same 30-volt full-scale voltmeter is connected to the supply voltage through the channel-selector switch. It is also possible to monitor and record the supply voltage by means of a 7-238 galvanometer. A locking potentiometer on the rear panel adjusts galvanometer deflection from 1.0 to 2.1 in. for any supply voltage from 22.0 to 28.5 volts. A connector is used for the monitoring galvanometer.

Any of four fixed calibration resistors in a 2:1 succ-



four-arm pickup bridge, each step doubling galvanometer deflection. In addition, a fifth position of the calibrate switch connects an external calibrate resistor of any desired cessive relationship, may be applied to either half of each value.

Each channel has a balancing potentiometer for adjustment of the bridge to a zero stress level, output being read on a 50-0-50 microampere balance meter. Three ranges of balance sensitivity may be used. After balancing, settings are protected against accidental changes by the locking-type controls. Polarity of each channel may be reversed by a two-position toggle switch on the front panel.

Consolidated Engineering Corp.,
300 N. Sierra Madre Villa, Pasadena 8, Calif.

Increased Safety in Measuring D-c Voltage

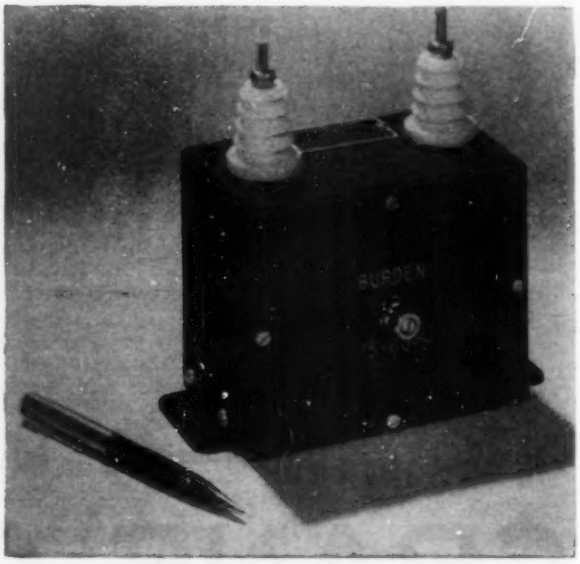
A d-c voltage measuring reactor has been designed to provide safety in the measurement of high d-c voltage by insulating the instrument circuit from the power source.

Developed for remote measurements of d-c voltages up to 1200 volts, the equipment consists of a saturable core reactor with a single d-c winding, two a-c windings, and proper range resistors. The d-c winding has a saturating effect on the core, and the a-c windings, supplied from a separate power source, deliver a rectified average current proportional to the degree of saturation of the core. A selenium bridge rectifier is used in the a-c circuit to permit interpretation of the average current.

A calibrating adjustment is used with the new device which gives final adjustment of the output current to the burden used. The reactor is designed to work into a burden with a nominal resistance of 25 ohms. The burden should not exceed a maximum resistance of 100 ohms.

Because of the heavy construction of the non-electronic device, it requires little maintenance. It has no moving parts. In addition, the use of the d-c voltage-measuring reactor allows reduction of initial instrumentation costs.

The d-c voltage-measuring reactor has a plus or minus accuracy of 0.5 percent of full scale, and operates on a power supply of 115 v, 60 cycles. The reactor measures 6½ in. x 6½ in. x 4 in. and weighs 2 lbs, 10 ounces.

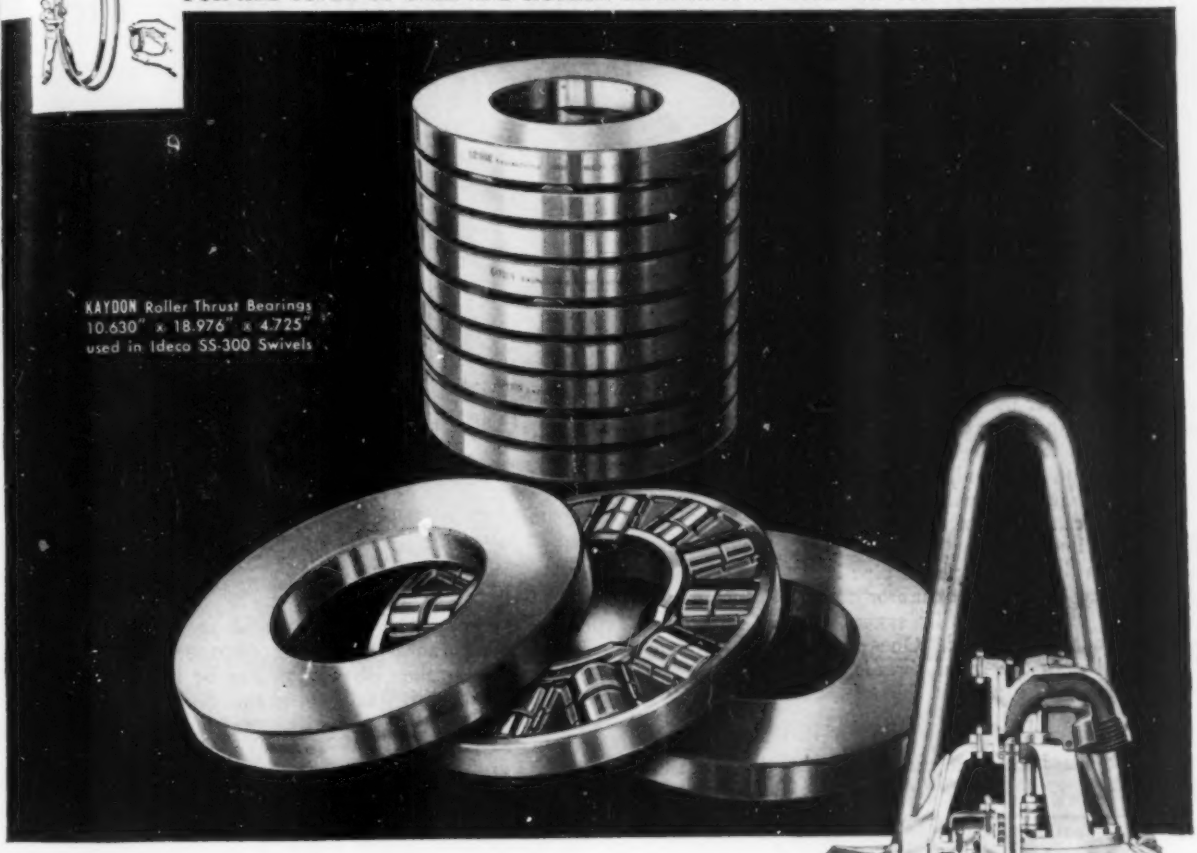


General Electric Co., 1 River Rd., Schenectady 5, N. Y.

CONTINUED ON PAGE 216

Contact KAYDON Muskegon

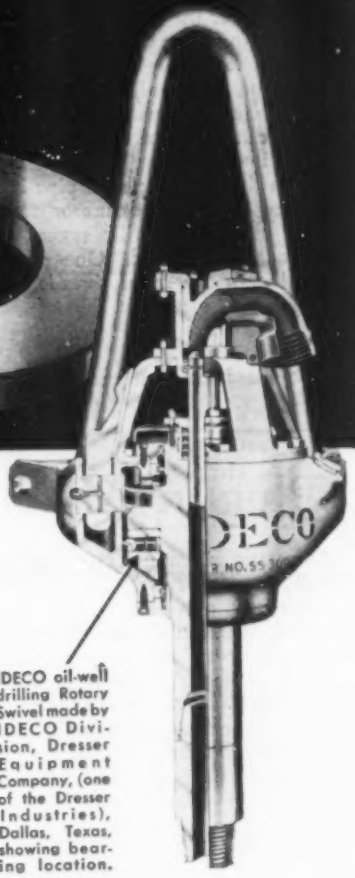
FOR ALL TYPES OF BALL AND ROLLER BEARINGS: 4" BORE TO 120" OUTSIDE DIAMETER



Takes 300-ton loads!

Dead-load capacities to 300 tons have been obtained, without added weight, in IDECO Streamlined Swivels for deep oil-well drilling. The success of these rotary swivels is the result of advanced engineering and years of experience in swivel manufacture. Rugged bearings are vital . . . husky **KAYDON** heavy-duty roller thrust bearings carry the full load.

In many other industries, machine designers find **KAYDON** bearings help make bigger machines possible, without unnecessary bulk and weight. If you have a bearing problem, contact **KAYDON** of Muskegon.



IDECO oil-well drilling Rotary Swivel made by IDECO Division, Dresser Equipment Company, (one of the Dresser Industries), Dallas, Texas, showing bearing location.

THE KAYDON ENGINEERING CORP.

KAYDON Types of Standard and Special Bearings:
Spherical Roller • Taper Roller • Ball Radial • Ball Thrust
• Roller Radial • Roller Thrust • Bi-Angular Bearings

MUSKEGON • MICHIGAN

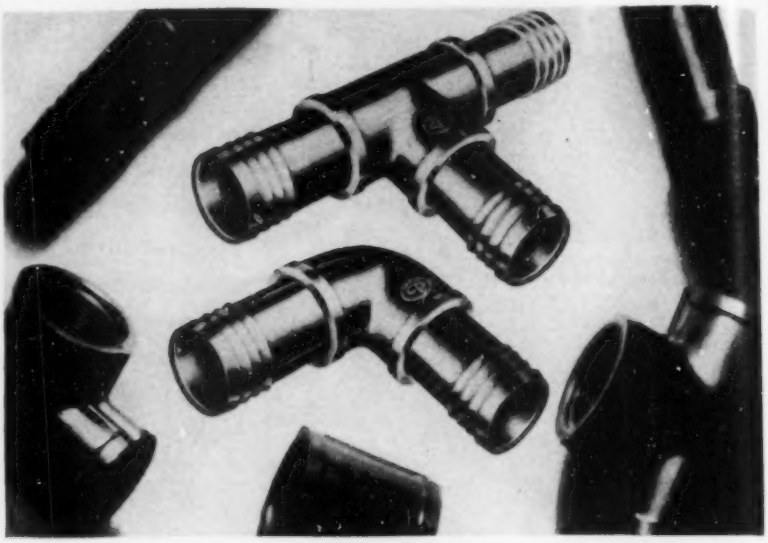
PRECISION BALL AND ROLLER BEARINGS

New Fittings for Connecting Flexible Plastic Pipe

With the development of new insert type ell and tee couplings for making sharp turns or take-offs from flexible plastic pipe lines, time and material are conserved in making leakproof connections, and one fitting now makes a connection which formerly required the use of three or four.

These new fittings are quickly joined in the same manner as previously used for insert couplings. Sections of pipe can be cut to the desired length with an ordinary hand saw and the fitting inserted. Stainless steel clamps are tightened over the pipe and fitting to draw the pipe down onto the serrations of the insert to give a positive, leakproof joint. The only tools required are a saw and screwdriver, and connections can be completed in less than two minutes.

When the flexible plastic pipe is to be joined to a metal fixture or a previously installed metallic system, an insert adapter is used. One end is screwed onto the metal threads, and then the plastic pipe is slipped over the serrated end and clamped securely. Adapters used I. P. T., which mate with standard female threads.



These new fittings, together with the straight insert coupling and threaded tees, ells and unions, make possible all types of installations with this flexible plastic pipe. All fittings are molded from a single piece of thermoplastic material and are said to be guaranteed against rot, rust and electrolytic corrosion. They are light in weight, can be handled easily, to save time, and give permanent, leakproof connections.

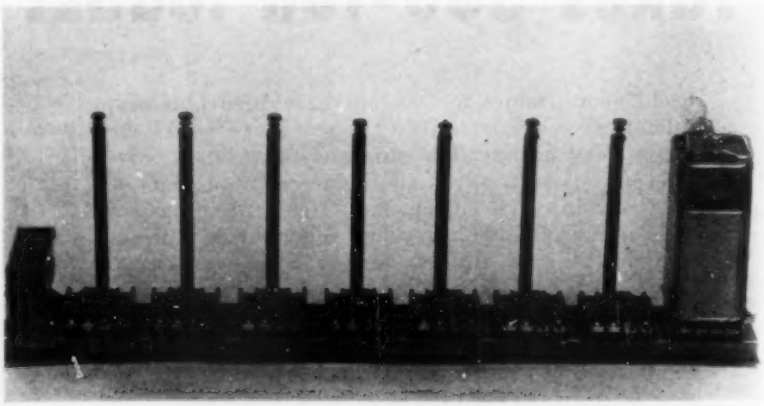
Carlon Products Corp.
10255 Meech Ave., Cleveland 5, Ohio

Plug-In Alarm Units Are Hermetically Sealed

Automatic alarm units for remote signalling of failure or other-than-normal operation of valves, pumps, heaters, and other kinds of equipment in process operations, have a special type of unitized construction which will permit a variety of circuit arrangements from one basic alarm unit. This is made possible by a switchboard circuit header which is wired into the basic relay in different ways, depending on the circuit desired.

Designed for class 1, div. 2 applications (or for all general purpose use) the hermetically sealed relay unit is the basic component. It is a fully self-contained assembly, filled with dry inert gas and hermetically sealed, and is available in over 50 standardized operational circuits.

The units are self-contained and plug in the chassis like a vacuum tube. The chassis is also standard, varying only in size to accommodate various multiples of the units. The uniform



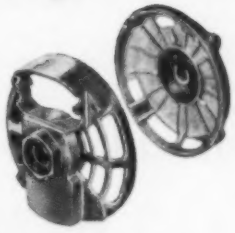
bus chassis wiring makes it possible to plug any circuit into the same chassis.

Two types of signal lights are available: backlighted nameplates, or giant turret lenses for two light systems. Both have 2 to 12 stations with an integral chassis, 2¼ x 3 in. engraved nameplates, and are illuminated by 2 six watt lamps. Clear visibility at great distances is said to be possible with the larger new type turret lens.

Tigerman Engineering Co.
4332 N. Western Ave., Chicago 18, Ill.

CONTINUED ON PAGE 218

creative castings

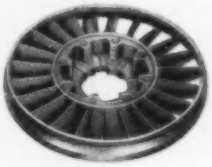


Motor End Frames

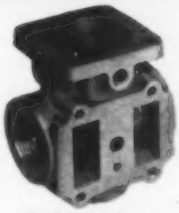
Gyrol Fluid Coupling

Garbage Disposer Housing

Aircraft Piston



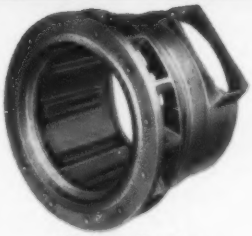
Torque Converter



Fuel Pump Body

Carbon Pile Regulator

Steel-Belted Piston



Alternator Housing

Diesel Permanent Mold Piston

Wing Actuator

Air Connector

Launching Barrel for Bazooka

For many years the foundry of Thompson's Light Metals Division quietly cast thousands and thousands of hard-to-make precision parts in light alloys of aluminum and magnesium.

Word got around that Thompson had the experience and facilities to cast light-weight, strong, heat-resisting alloy parts in permanent molds and high pressure dies—which eliminated the weight problems of ferrous counterparts. One by one manufacturers came to Thompson for help and advice when they learned that the close tolerances achieved by Thompson cut machining and finishing costs.

Today, our capacity is channeled to top-rated jobs. We're building additional facilities as fast as possible and, in the meantime, Thompson services, as always, are at your command. Our entire staff of creative engineers is ready to help you plan new parts or re-design old ones for the future.

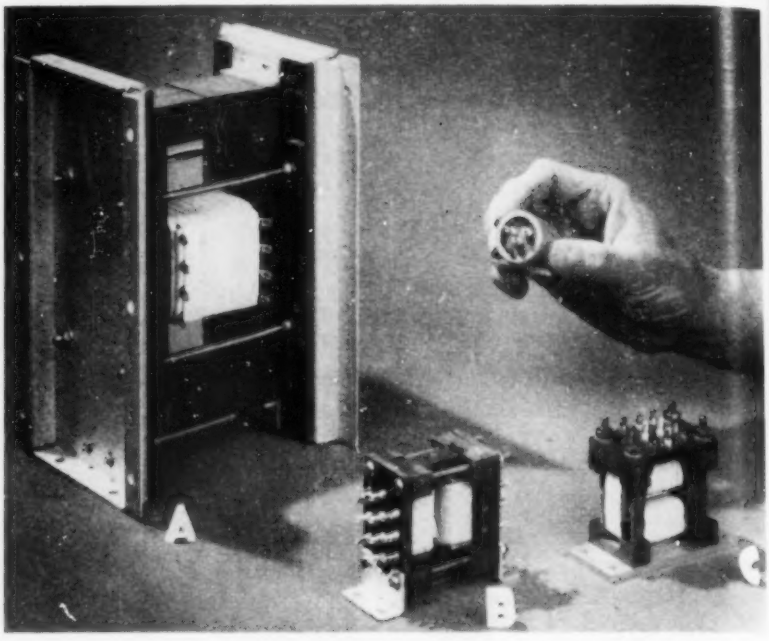
A THOMPSON STORY TOO BIG TO HIDE!

Thompson Products, Inc.

2269 Ashland Road • Cleveland 3, Ohio

LIGHT METALS DIVISION

Broadband Ferrite-Core Transformers



Taking advantage of a new design technique based on ferrite magnetic cores and tetrafluoroethylene insulation, a line of specialized transformers is being offered, giving application advantages: (1) where r-f circuitry requires impedance matching over a wide impedance and/or frequency range; (2) where r-f or audio applications require electrostatic shielding between windings, high voltages, or especially small dimensions.

Typical designs shown in the illustration include:

A. A grid-driving transformer with 600 ohm input for 3 kw, 1,350 v rms, 2.24 amp and an output of 4,500 v rms across 6,750 ohms. Response is flat within 0.1 db from 30 kc to 1.2 mc and efficiency at 30 kc is 98 percent.

B. A high-voltage grid-driving transformer with 50 ohm input for 2.5 watts, 11.1 v rms, and a double 100v rms output from two windings separated by 3,300 v rms. Response is flat within ± 1.5 db from 30 kc to 2 mc.

C. A push-pull output transformer with 4 watt input and output to a 50 ohm line. Response is flat within 1 db from 20 kc to 1 mc.

D. (Shown in hand) Line-balancing transformer, from 500 ohm unbalanced input to 500 ohm balanced output. Response is flat within ± 3 db from 13 kc to 4.5 mc.

In these types the core material and insulation used combine high efficiency with low leakage inductance and low distributed capacitance resulting in roughly a four-times increase in voltage-handling capacity over an equivalent conventional iron-core transformer. Leakage reactance of these types run approximately 10 percent that of equivalent conventional transformers. Size and weight are less than those of conventional types.

Functionally, the transformers are said to be capable of operation with internal temperatures up to 160 C and are not damaged by moisture absorption or fungus attack.

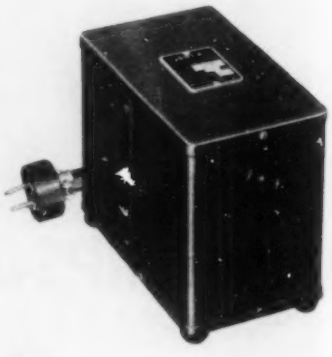
Sierra Electronic Corp., 830 *Brittan Ave., San Carlos, Calif.*

Automatic Single-Step Voltage Booster

This automatic voltage booster is a single-step unit of sufficient rating to handle motor starting loads in areas where fluctuating low voltages are common. This device is designed primarily for such motor-operated appliances as: refrigerators, air-conditioners, pumps, milking machines, separators, and beverage dispensers, and could be used in rural areas and export market areas where low voltage periods have been causing unreliable performance, or motor damage.

The new booster is completely automatic in operation, and will cut into the circuit if the line voltage drops to about 105 v or below. When the line voltage rises to about 110 volts or more, the booster is automatically disconnected. The voltage booster plugs into the regular line outlet, and the motor power cord into the booster socket. The unit is portable and may be used for any number of machines because of its plug-in connection. It does not require wiring or installation.

Specifications for model 92004 are: load capacity 2KVA; approximate voltage boost 12 percent; pull-in, 105 v drop-out 110 v; length 8 in.; width 5 in.; height 7 inches. The measurements for model 92005 are: 16 x 6 x 6 in.; with the load capacity 5 KVA. All other specifications are same as for the model 92004. Other capacities and voltage ratings, as well as 50 cycle frequency units can be designed for reasonable volume requirements.



Sola Electric Co.
4633 *West* 16 *St., Chicago* 50, *Ill.*

CONTINUED ON PAGE 220

ALLOY PRECISION Castings Company

EAST 45th ST. AND HAMILTON AVE. • CLEVELAND 14, OHIO

Important
Pass this on!

To Executives Charged with Responsibilities
of Design, Development and Production:

This is intended to call your attention to the Mercast frozen mercury process of investment casting — a development that manufacturers find helpful in solving difficult design and production problems. We suggest that you immediately investigate this versatile process which makes available one-piece shapes previously impossible to cast or machine. Get this!

Frozen mercury patterns and our special ceramic investment material permit surface finishes and dimensional tolerances never before available in foundry production. For example, ±.002 to .003" per inch is consistently held. In many applications, our castings require no finish machining. Some mercastings, with intricate shapes and cavities, were previously fabricated parts which required expensive machining and assembly, or were too costly to make at all. Big savings here... up to 78%

PLASTIC MOLD CAVITY BLOCKS?

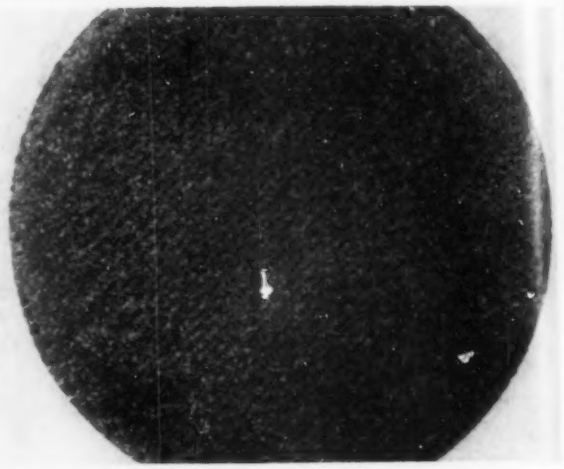
Our metallurgists can help you get mass production in such hard-to-machine metals as pure nickel, Hastalloy B, Rexalloy 108, stainless, Stellite, and others, both ferrous and nonferrous, at exceptionally close tolerances. Current applications — radar, aircraft, automotive, electrical, and machinery — indicate the wide, economical adaptability of mercasting. Here may be the answer to your problems involving design ... materials ... costs ... weight ... time ... machining capacity. this hits home

If this discussion suggests use of mercastings by your company, write to Dept. A-2 for Bulletin 706 — or tell us your specific problems. Our metallurgists and Mercast engineers will be glad to serve you.

Sincerely,
Alloy Precision Castings Company
Alloy Precision Castings Company

Drop a note today!
Send those tough problems...

High Strength Cork Gasketing Material



Made by a modification of the beater saturation process, new fiber gasketing materials called accopac, have high compressibility, combined with high crush resistance, imperviousness, flexibility, uniformity, and other qualities.

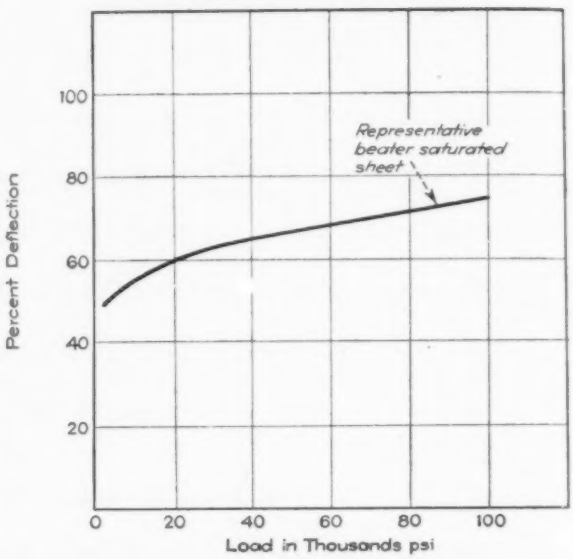
The beater saturation method treats the fibers with water dispersions of rubber or resin, distributing an even coat over each fiber before the sheet is formed, and giving the sheet a homogeneous quality. The new process is said to permit the deposition of larger amounts of saturant on the fibers than was possible with the conventional bath method. With the new process, different types of fibers, saturants, and fillers may be combined.

Among the advantages of these new materials are: they will not dry out, harden, or shrink on aging or in service; they have high compressibility which gives good sealing even under light flange pressures; they will not rupture or crush under flange pressure loads of 100,000 psi; they are homogeneous and impervious, and will hold internal pressures of from 1,000 to 2,000 pounds per square in., depending on the grade of the gasket material and the flange pressure; they are flexible and will not crack.

One group of these materials, made of cellulose fibers, finely ground cork, and synthetic rubber, is recommended for sealing liquids and gases at temperatures up to 250 F. The materials are available in three grades, in sheet, roll, and ribbon form, and in cut gaskets and washers.

Asbestos sheets also are available. They are composed of crysotile asbestos and Buna N type synthetic rubber binder, and are recommended for sealing liquids and gases at temperatures up to 750 F. These asbestos materials, which are available in sheet and continuous roll and ribbon form, are homogeneous and non-directional, with a compressibility of 30 to 35 percent under a load of 2,800 lbs per square in.; and will not crush and leak even under flange pressures of 100,000 psi; can be bent double without cracking or losing thear sealing properties.

Armstrong Cork Co., Lancaster, Pa.

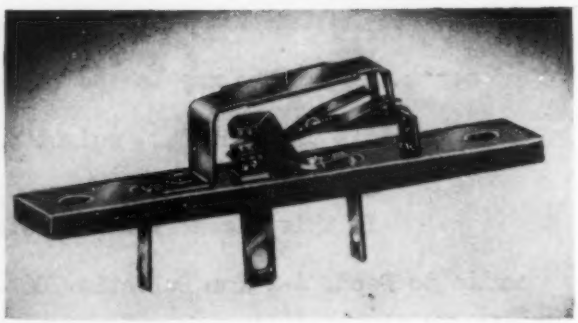


Small Size, Open Blade, Snap-Acting Switch

A new switch is said to offer the answer to all control problems wherever electrically operated apparatus has limited space for switch installations.

Requiring space only $1\frac{1}{4}$ by $\frac{5}{16}$ by $\frac{3}{8}$ in., exclusive of the terminals and terminal strip, this miniature switch will handle resistive loads of 10 amp at 125 v a-c, and 5 amp at 250 v a-c. The contacts have positive wiping action that makes the switch adaptable for use with tungsten filament lamp loads. A feature is the use of terminals integral with the contact supports. This gives a lower series resistance with consequent less heating, at maximum load.

It operates on close movement differential, and requires only a few ounces for an actuating force. The single-pole, double-throw contacts let any type E switch be used for the normally open or normally closed circuit control.



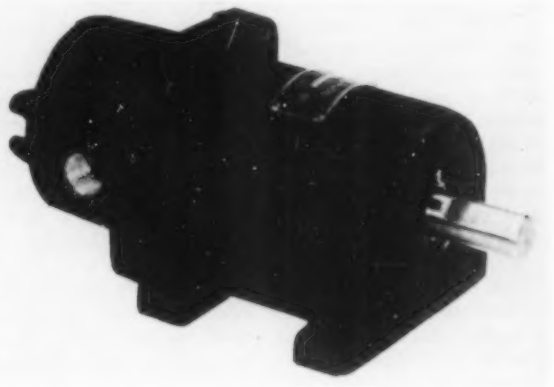
W. L. Maxson Corp., Unimax Switch Div., 460 W. 34 St., New York 1, N. Y.

CONTINUED ON PAGE 223

Heavy Duty Speed Measuring Heads

Heavy duty tachometer heads, when used with the tachometer indicators, recorders, or controls, may be used for a wide range of speeds, and may be used for measuring speeds of rubber extruders, metal working machines, ball mills, cement kilns, and similar installations. Speeds between 200 and 10,000 rpm for full scale indication are measured by these heads, and they can be overspeeded 2 to 10 times without damage.

The stainless steel head shaft is $\frac{3}{4}$ in. in diameter, and supported in large, sealed ball bearings. The head casting is anodized aluminum having $\frac{3}{8}$ in. wall and heavy mounting feet to give stability of inital alignment. All working parts and terminals are sealed against dirt, abrasives, and splashing liquids. Electrical connections between the head and speed indicator can be up to 1000 feet or more, with provisions for using conduit or armored cable. All heads of the same type number are completely interchangeable and require no special matchings or adjustments.



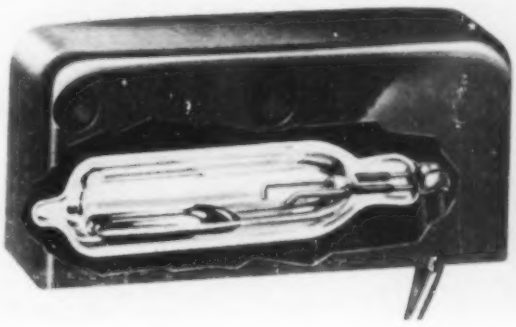
Metron Instrument Co., 432 Lincoln St., Denver 9, Colo.

Mercury Switch in Plastic Potting

Although standard glass-enclosed mercury switches are sufficiently rugged for most switching jobs, newly designed mercury switches embedded in plastic potting compounds for added protection have many applications that require additional protection against mechanical shock or impact. In addition to being stronger, these designs also are said to offer new methods of mounting mercury switches.

The first of these new mercury switch assemblies is the IMPI switch, whose overall size is $2\frac{1}{2}$ in. long, $\frac{3}{4}$ in. wide, and $1\frac{1}{8}$ in. high. This unit has less than 1 deg. differential angle, with an electrical rating of 2 amp 115 a-c; or 1 amp 115 d-c. Contact arrangement is single-pole, normally open. Mounting holes have been provided for $\frac{1}{4}$ in. mounting screws and pins.

In the mercury switch line there are more than 90 tube designs from which to choose size, variations in differential angle, electrical capacity, and contact arrangement.



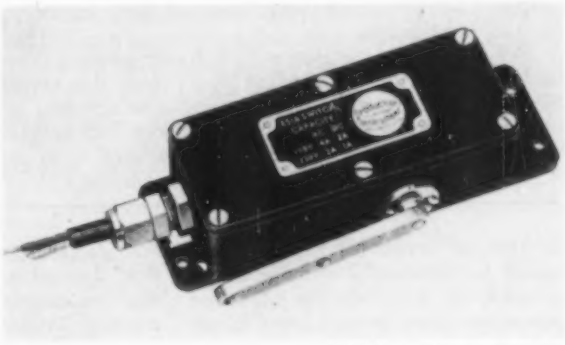
Micro Switch, Freeport, Illinois

Long Life Switch for Electric Counter Use

Designed to withstand millions of operations, this heavy duty electric switch may be operated by reciprocal motion or by complete revolution of the shaft. Although it was developed especially for electric counter actuation, it is adaptable to other applications where electrical operations need to be synchronized with mechanical operations.

Reciprocal operation requires an arm movement of 20 deg minimum, 340 deg maximum. In rotary operation, the switch is closed 140 deg and open 220 deg of each revolution. Arm position is adjustable. Operating torque, 2 in.-oz. minimum.

The contact springs are nickle silver with silver points. Oversize bearings, and heavy steel shaft with steel operating arm are used. Rated at 10 amp, 115 v, or 5 amp at 230 v, a-c, the switch measures: 6 in. x $1\frac{7}{8}$ in. x $1\frac{9}{16}$ deep. It can be furnished equipped with measuring wheels.



Production Instrument Co., 702-10 W. Jackson Blvd., Chicago 6, Ill.

CONTINUED ON PAGE 224

High Strength Cork Gasketing Materi-[1]

Made by a modification of the beat new fiber gasketing materials called compressibility, combined with high perviousness, flexibility, uniformity, ar

The beater saturation method treats dispersions of rubber or resin, distri over each fiber before the sheet is for sheet a homogeneous quality. The ne permit the deposition of larger amo the fibers than was possible with th method. With the new process, diffe saturants, and fillers may be combinec

Among the advantages of these new will not dry out, harden, or shrink on they have high compressibility which even under light flange pressures; they crush under flange pressure loads of 1(homogeneous and impervious, and will sures of from 1,000 to 2,000 poun depending on the grade of the gaske flange pressure; they are flexible and

One group of these materials, made finely ground cork, and synthetic rubbe for sealing liquids and gases at tempera The materials are available in three gra and ribbon form, and in cut gaskets and

Asbestos sheets also are available. T of crysotile asbestos and Buna N typ binder, and are recommended for se gases at temperatures up to 750 F. These which are available in sheet and continuc form, are homogeneous and non-directi pressibility of 30 to 35 percent under a per square in.; and will not crush and flange pressures of 100,000 psi; can be be cracking or losing thear sealing propertie

Armstrong Cork

Small Size, O[1]

A new switch is said to offer the answ problems wherever electrically operated a[1] ited space for switch installations.

Requiring space only 1¼ by $\frac{5}{16}$ by ⅜ the terminals and terminal strip, this mini handle resistive loads of 10 amp at 125 v at 250 v a-c. The contacts have positiv that makes the switch adaptable for us filament lamp loads. A feature is the u integral with the contact supports. This series resistance with consequent less heati load.

It operates on close movement differential, and requires only a few ounces for an actuating force. The single-pole, double-throw contacts let any type E switch be used for the normally open or normally closed circuit control.

W. L. Maxson Corp., Unimax Switch Div., 460 W. 34 St., New York 1, N. Y.

CONTINUED ON PAGE 223

Heavy Duty Speed Measuring Heads

Heavy duty tachometer heads, when used with the

., 432 *Lincoln St., Denver 9, Colo.*

Micro Switch, Freeport, Illinois

Use

Oversize bearings, and heavy steel shaft with steel operating arm are used. Rated at 10 amp, 115 v, or 5 amp at 230 v, a-c, the switch measures: 6 in. x $1\frac{7}{8}$ in. x $1\frac{9}{16}$ deep. It can be furnished equipped with measuring wheels.

Production Instrument Co.,
702-10 W. Jackson Blvd., Chicago 6, Ill.

CONTINUED ON PAGE 224

Silicone Rubber Impregnated Fiberglass

Arcosil 2184, a recent line of silicone rubber impregnated fiberglass materials developed to meet the need for ducting, sleeves, and couplings with resistance to high and low temperatures, combines a newly developed silicone rubber compound with improved fabrication techniques. Items manufactured from this material are said to withstand temperatures as high as 700 F, and remain flexible at —125 F, resist aging, ozon, and most corrosive fluids and gases. The new silicone rubber compound used is said to be several times more resistant to abrasion than any previous silicone rubber material.

An important characteristic of the new material is that it lends itself readily to the forming of both simple and complex shapes. This has made possible new and improved fabrication methods. In addition, ducts fabricated from the new material have less leakage.

Items now in production and available as standard and custom-made parts include: helical wire supported flexible ducting and tubing in all diameters for high and low pressure applications; convoluted and sleeve-type flexible couplings for hot air ducts; high pressure-high temperature hose suitable for handling hot air at 700 F and 2000 psi; die-cut high temperature gaskets; and fabric-covered sponge silicone seals for high and low temperature sealing applications. The material can be bonded to metal and parts can be fabricated with built-in T's, elbows, flanges and other special features.

Arrowhead Rubber Co., Downey, Calif.

Measures Surface Electrical Resistance Directly

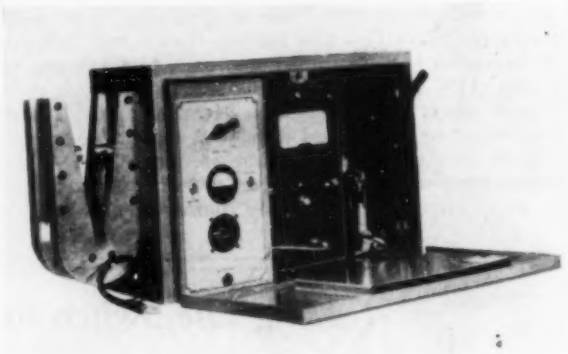
A device that measures the surface electrical resistance, directly in microhms, was primarily designed for measuring the resistance of aluminum; however, other materials with low surface resistance may also be measured.

The indicator can directly measure the total surface resistance of two sheets, or coupons, when placed between two self-contained electrodes. Resistance values of 0 to 100 microhms can be read directly. Resistance of 100 to 1000 microhms may be read indirectly.

Resistance as low as one-millionth of an ohm (0.000001) can be measured on a direct reading linear scale calibrated 0 to 100 microhms. Values of 10, 15, 20 microhms can be read as easily as 100.

The surface resistance indicator shown contains a V or C type yoke to accommodate aluminum sheet or large coupon. The distance between center of press and bottom of yoke is 5½ inches.

The indicator is complete with hydraulic pressure device and pressure gage, 3 in. standard copper electrodes, vacuum tube d-c. millivoltmeter, resistance indicator adjuster, and d-c power source with suitable voltmeter and indicator bulb. The d-c source consists of a standard 6 v, 100 amp/hr automotive storage battery. A battery charger is supplied, mounted, and interwired.



The components are mounted in a cabinet 13 in. high, 20 in. wide, and 10 in. deep.

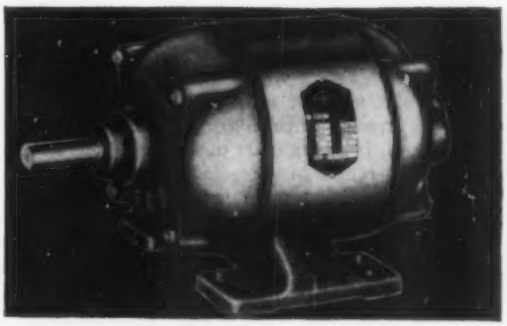
Weltronic Co., 19500 W. Eight Mile Road, Detroit 19, Mich.

A TORQUE SCREW-DRIVER, especially suited for electronics equipment and assembly is available in sizes for torque measurement from 0 to 6 in.-oz, to 0 to 24 in.-ounces. Apco Mossberg Co., 224 Lamb St., Attleboro, Mass.

POROUS STAINLESS STEEL GAGE SNUBBERS that use a porous stainless steel disk for damping pulsating pressures are now available for high pressure service. The snubbers are made in ¼ in. SPT, and ½ in. SPT. Standard body materials are 18-8 stainless steel and brass. The stainless steel bodies are rated at 20,000 psi operating pressure, and the brass bodies at 15,000 psi. Equipoise Controls, Inc., P. O. Box 269, Bronxville, N. Y.

CONTINUED ON PAGE 226

Big overload capacity



General-purpose motors. A widely varied selection of *Capacitor-Start*, *Split-Phase* and *Poly-Phase Motors*.

Special-purpose motors. With specific mechanical and electrical characteristics for pumps, oil burners, fans and blowers. Motors that in all probability will meet your requirements "as is."

Ask your distributor, or write us direct.

It isn't put there for steady use. But heavy-duty Hoover Motors have an overload capacity that makes each one of them a working giant in a small package.

Like those last miles of speed in your automobile, this overload capacity is a safety reserve beyond usual needs. And it's good to know you have it.

You see its benefits in smoother, faster starts for hard-to-start machinery—in running speeds that remain almost constant even with wide variations in load.

And because of this greater in-built capacity, Hoover Motors run cooler, stay quieter on the job, and keep their youthful vigor through a long, full life.

And service? *When* you need it, *where* you need it. Hoover service facilities are world-wide—always ready to protect your customers and to guard your good name.

Hoover® Electric Motors

since 1934

THE HOOVER COMPANY

Kingston-Conley Division

92 Brook Avenue, North Plainfield, New Jersey

Electromagnetic Pump for Molten Metals

An a-c electromagnetic pump with no moving parts, for pumping liquid metals and other low resistance conducting fluids at temperatures up to 1000 F, can be used to move any conducting fluid that has a specific resistance equal to or less than stainless steel (approximately 90 microhm-cm). Liquid metals such as sodium, sodium-potassium, alloys, and lithium will fall in this classification.

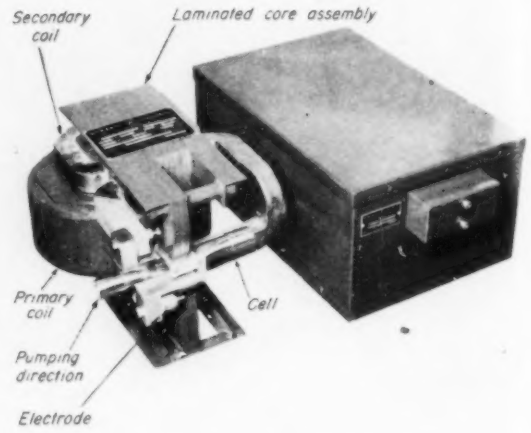
The new pump operates on the principle that a current-carrying conductor in a magnetic field is acted on by a force. In this case, the fluid serves as the conductor, so that when current and flux are properly applied, pumping occurs.

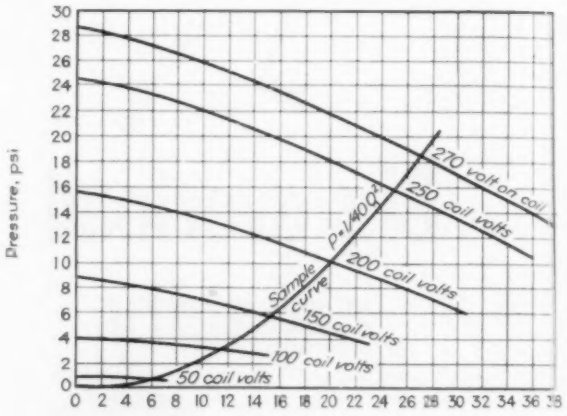
One of the three basic elements of the pump, a transformer unit, sets up a high current through the liquid metal and, simultaneously, a magnetic field perpendicular to that current. A cell unit, which consists of a flattened stainless-steel pipe, carries the liquid metal through the magnetic field. Since contact is made from the copper to the liquid metal through a thin wall of stainless steel, the liquid must wet the wall to permit a high current to flow. The fluid must be fed into the inlet of the cell with sufficient head to keep the cell full. The third basic part, a capacitor unit, which consists of 500 μf in parallel with the primary of the transformer unit, gives the power factor correction.

The amount of liquid metal which can be pumped in a given period varies with the pressure. At 20 psi, the pump is able to move approximately 28 gallons of molten metal per minute, according to the manufacturers. Shown in the graph is a typical set of operating curves for the a-c electromagnetic pump.

The transformer unit of the new electromagnetic pump is 19 x 13 x 12 in., the capacitor unit 22 x 15 x 10 in., and the cell is one in. standard pipe of number 347 stainless-steel, 10 in. long. The equipment operates on 230 volts at 30 amperes.

General Electric Co., 1 River Rd., Schenectady 5, N. Y.





Magnetically Operated Level Limit Switch

Originally designed for aviation fuel level control, a new line of level limit switches have been used in the control of liquid levels in the beverage, chemical food, fuel, and other liquid-processing industries.

The limit switch uses an hermetically sealed, magnetically operated switch, minimizing the false alarms caused by agitated solutions and vibrations. The switch is not affected by high altitude nor acceleration, and no springs are used. Fourteen models, having variations in mountings, materials, and floats, are available for aircraft use.

The weight and mass of the non-absorbent nylon float are not affected by moisture, and will give an accurate reaction throughout the life of the switch. The aircraft model is supported by an aluminum body casting. The actuating magnet, incorporated in a counterweight, is positioned by the statically balanced float which opens or closes the electrical circuit at a pre-set liquid level.

Revere Corp. of America, Wallingford, Conn.

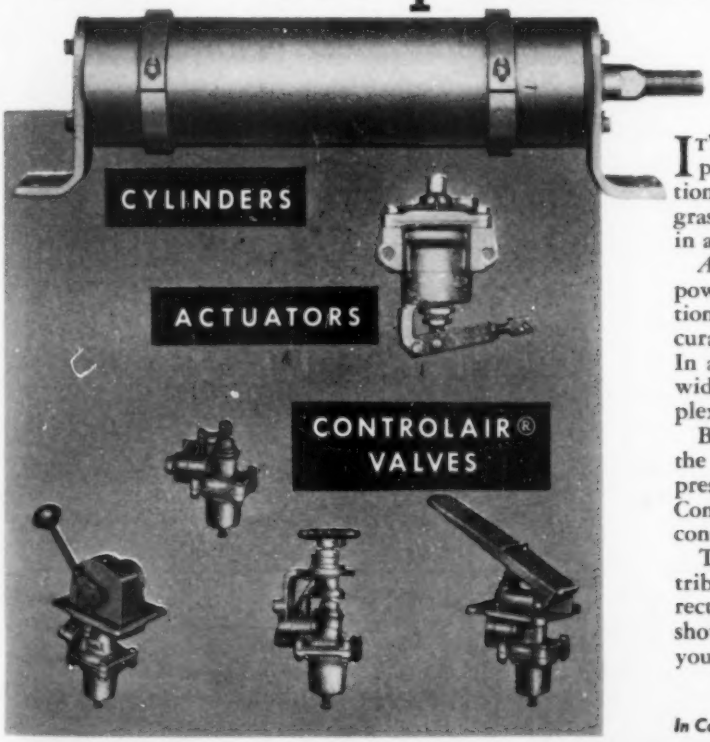
CONTINUED ON PAGE 228

want to clamp something

...or position it?

use these

low cost pneumatic muscles



IT'S hard to find a machine that doesn't require powerful, linear motion in some part of its operation. Clutches must be engaged, objects must be grasped and held fast, heavy loads have to be moved in a straight line.

Air is the answer. Pneumatic cylinders exert powerful, cushioned force for any holding operation. Pneumatic actuators allow hair-splitting accuracy if you want to position something exactly. In addition, you have your choice between a very wide range of air controls that permit the most complex interconnected assemblies.

But the best part is this: you can buy everything, the cylinders, actuators, control valves *and* the compressor from one company, Westinghouse Air Brake Company, world leader in engineered pneumatic control systems.

There's a Westinghouse Air Brake Company distributor near you; just look in your Classified Directory under "Air Compressors." He'll be glad to show you how Westinghouse components can help you engineer a better product.

Factory Branch: Emeryville, Calif.
In Canada: Canadian Westinghouse Co., Ltd., Hamilton, Ontario

INDUSTRIAL PRODUCTS DIVISION
WESTINGHOUSE
AIR BRAKE COMPANY
WILMERDING, PENNA.

New Line of Heavy Duty Connectors

Design and construction of the AO line of heavy duty plugs and receptacles, make them adaptable for the extreme conditions of temperature, moisture, dust, vibration and shock found in the operation of military equipment. The plug and receptacle types follow, in general, the basic design of the standard AN and associated types, although their construction has been simplified for rugged use.

Insulators are made of special resilient materials 65-70 shore hardness with good dielectric qualities. Shells are aluminum alloy with cadmium plate and natural iridite finish.

Contact arrangement of insulators follow the design of standard AN insert drawings. The contacts are high conductive material, silver plated. Both pin and socket contacts may be removed for soldering.

Waterproof tested at 250 F for 70 hrs. with insert material indicating no signs of decomposition or tackiness. In place of the usual endbell found in most aircraft connectors, a grommet retaining nut fits over the grommet and terminals to give a weatherproof cable entry seal.

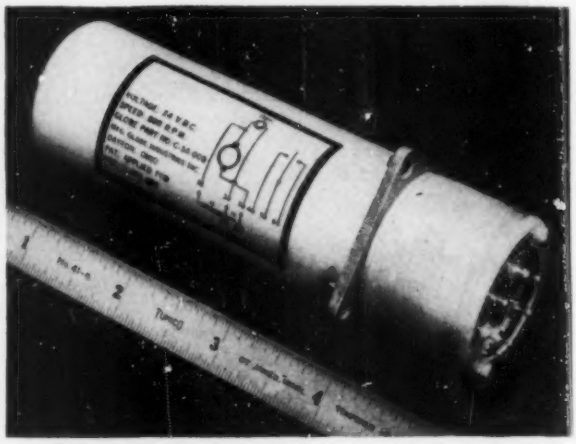
Cannon Electric Company, 3209 Humboldt St., Los Angeles 31, Cal.

High Speed Motorized Switch

A motorized switch has been developed that will interrupt an inductive, high current load to introduce an activating signal in a control circuit, or any circuit where high speed single pole double throw switching action is desired.

The motorized switch is a combination of the moto-mite motor, governor controlled if required, a small concentric gear reduction and a single pole double throw switch mechanism. Gear trains of 23 gear ratios are available for switch speeds of from 0.6 C.P.M. to 500 C.P.M. The governor can control the speed accurately over a wide range of input voltages. The actual size is 4½ in. x 1⅜ in. including governor for an 800 C.P.M. unit. The weight is approximately 9 ounces. The motor voltage ranges from 6 to 90 v d-c. The motor switch features heavy duty tungsten contacts, wiping action on contacts, and positive make and break of contacts. All switch and motor connections are located at the top on the terminal block.

The switch capacity is 450 watts. It is available with a speed governor, for close speed control at varying motor voltage. The unit is flange mounted in a 1½ in. square.



Globe Industries, Inc., 125 Sunrise Place, Dayton 7, Ohio

MANUFACTURERS OF FILTERS for high temperature and high altitude application are now supplying filters especially designed for noise attenuation from 14 kc to 1000 mc wide in a variety of circuits. With metallized paper capacitor sections and specially wound inductance, desired characteristics of high impedance, low voltage drop, and minimum heating can be obtained. Astron Corp., 255 Grant Ave., East Newark, New Jersey.

POWER OUTPUT of the standard line of saturable transformers is phase reversible a-c with output levels of one watt to one kilowatt, both 60 and 400 cps. Both open type and hermetically sealed units are available. Ambient temperature limits are from —60 C to over +80 C. Speed of response of these circuits is in the order of 1 to 5 milliseconds. Magnetic Amplifiers, Inc., 11-54 44th Drive, Long Island City, New York.

A NEW DEVELOPMENT in single phase variable speed motors in fractional horsepower is designated as type VA-C varidrive, and is made in ¼, ⅓, ½, and ¾ hp. The new motor uses 110 or 220 v, and has speeds in a 10:1 ratio with the range from 4 to 10,000 rpm. A control dial will change the motor's speed without stopping, eliminating an external speed changing device. U. S. Electrical Motors, Inc., Box 2058, Los Angeles 54, Calif.

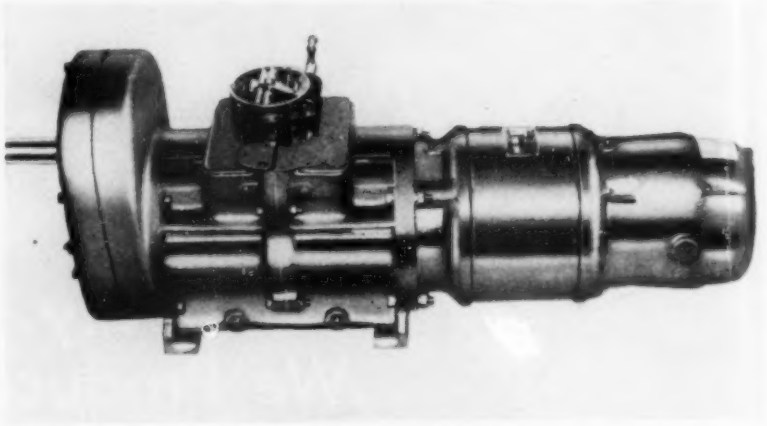
CONTINUED ON PAGE 230

You Specify..
..We Produce
Eastern Tool & Manufacturing Co. is completely equipped with automatic machinery and staffed with experts for the production of wire forms, metal specialties and close tolerance deep-drawing.
We are ready to handle a wide variety of wire and metal sizes and shapes, both ferrous and non-ferrous, from specifications to finished product. May we quote on your requirements?
Send for Bulletin No. 100
Precision Deep-Drawing
Eastern Tool & Mfg. Co. · Belleville 9, New Jersey

Brake Motor in Variable Speed Transmission Unit

A new type of brake motor is now available for use with a line of transmissions in sizes from ¼ to 3 hp. The 2 and 3 hp model shown in the photograph is available with or without the motor.

The built-in brake motor provides for the immediate stops required in indexing and positioning work. This feature, plus the other advantages in the drive, such as wide speed range with exact speed holding and ability to reset at a given speed, are said to make the unit well suited for applications requiring high accuracy. These applications include metering and proportioning work and jobs where the speed of one part of a materials handling system must be synchronized with another part.



The transmission, in all sizes from ⅛ to 3 hp, is available with or without built-in reduction of worm of helical spur types. A wide range of controls, including micrometer, lever and remote electrical may be had. The complete assembly of transmission, built-in motor with or without brake, built-in reducer and control, mounts with only four bolts, and is more compact than if each element were to be mounted separately. The transmission has built-in overload protection to prevent damage to the unit or to other parts of the power transmission system in case of a jam in the driven equipment.

The new brake is a direct acting disk type with rugged design, fewer parts, smooth and instant action, cooler operation and no solenoid or mechanical linkages. Motor and brake are connected in parallel. Starting the motor simultaneously energizes the magnet coils. The magnet attracts the magnet armatures which are attached to the pressure plate, compressing the springs and releasing the pressure on the disks. Stopping the motor de-energizes the coils. The spring tension then forces the pressure plate back, applying steady pressure to the disks, and quickly stopping and holding the load.

Graham Transmissions, Inc., 3754 N. Holton St., Milwaukee 12, Wis.

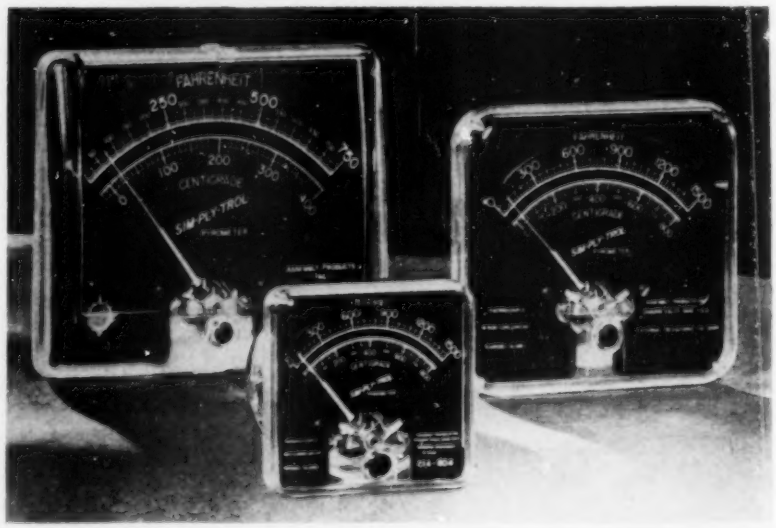
Black Face Pyrometers In Three Ranges

Clear, plastic case instruments with black dial faces are made in three sizes and nine standard temperature ranges for measurements from minus 200 to plus 3000 F. The corresponding Centigrade is shown.

Automatic cold junction compensation is accomplished with a bimetal spiral on the bottom torsion spring. A variable permiability magnetic shunt across the poles of the magnet corrects for copper error.

The millivoltmeter movements are medium high sensitivity at four ohms per millivolt (222 ohms for 2500 F). They may be supplied with calibration for any standard type of thermocouple. A calibrating resistor is included for adjusting the meter to different length of thermocouple leads.

The clear plastic front cover is a one piece construction and snap fit to the case. The case is free to breathe with changes in atmospheric pressure.



The three sizes are: model 451, 4½ in.; model 351, 3¾ in.; and model 261, 2½ inch. All are for semi-flush mounting in non-magnetic material.

Assembly Products Inc., Chagrin Falls, Ohio

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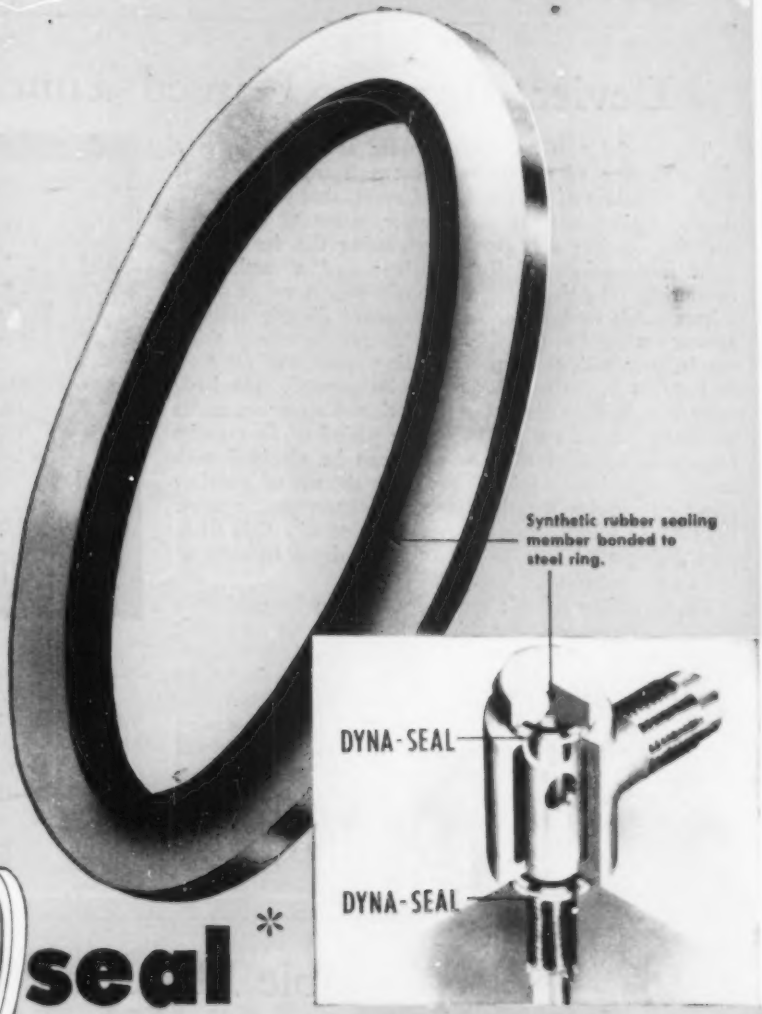
PRP announces a New Product

...the Dyna-Seal*



thoroughly proved — a simple face-to-face seal!

*trademark registered
U.S. Patent 2,455,982

Synthetic rubber sealing member bonded to steel ring for sealing circular flat surfaces, bolt heads, rivet heads, flanges, special fittings — no grooves necessary. Seals all pressures against water, all types of petroleum products, many other fluids and gases. Countless applications. Write for free handbook.

Precision Rubber Products CORPORATION

The "O" Ring Specialists

Dept. 3, Oakridge Drive, Dayton 7, Ohio

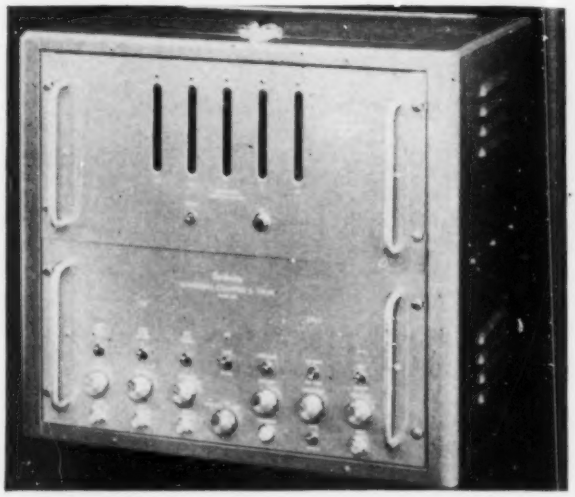
Device Measures Elapsed Time Between Events

The model 550 universal counter and timer gives a direct reading of elapsed time between any two events; a direct reading of the number of events that occur during a precise time interval; an accurate means of measuring low frequencies; a means of measuring the duration of light interruptions of light flashes; and a method of measuring velocities. Time intervals over a range of 10 microseconds to 1 sec. can be measured directly with an accuracy of ±10 microseconds. Events occurring either regularly or with random distribution at rates of from 20 to 100,000 events per second can be counted. The basic error is ±1 event, therefore at maximum range accuracies of 0.001 percent are possible. The period of frequencies from zero c.p.s. to 100,000 c.p.s. can be obtained with an accuracy of ±10 microseconds. By the use of auxiliary photocell attachments the interval between two separate light flashes may be timed, or the duration of a light flash, or a dark period may be determined with an accuracy of ±10 microseconds.

The flexibility of this unit permits it to be used as a precision frequency measuring device, as an electronic tachometer, as a secondary frequency standard, as a means of measuring the ratio of two independent variables, or as a multi-purpose general laboratory instrument. The direct decimal presentation of results eliminates conversion and lessens the possibility of resultant error. The unit will automatically and continuously count and display results.

Input requirements:

Events per unit time channel: any positive wave shape, amplitude 0.2 to 50 v r.m.s. Input impedance 0.05 micro micro farad condenser in series with 250 K potentiometer.



Time interval pulse channel: either positive or negative pulses with a rise time of 1 v per microsecond or better. Maximum sensitivity 1 v peak. Input 100K potentiometer.

Time interval photo-wave channel: maximum sensitivity 0.5 v r.m.s. Either positive or negative waves.

Berkeley Scientific Corporation,
2200 Wright Ave., Richmond, Calif.

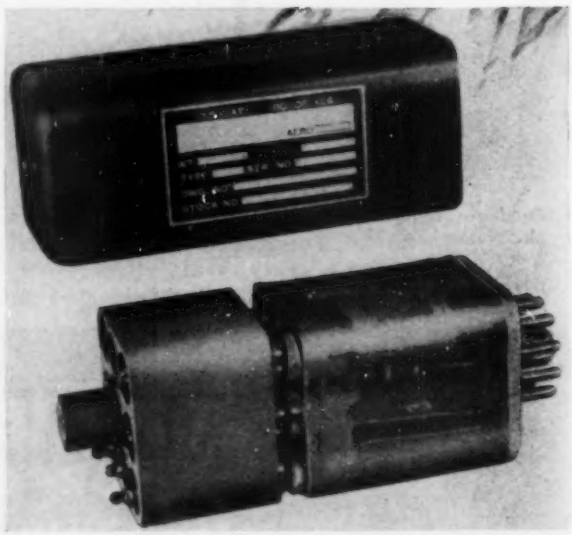
Plug-In Replaceable Electronic Subassemblies

A replaceable electronic subassembly, suitable for sub-miniaturizing vacuum tube circuits such as multivibrators, analog computing amplifiers, and counting chains, is being manufactured to meet demands for reduction in size and weight to make room for fuel and armament, in military craft. The unit is suitable for operation under conditions of vibration, temperature, and humidity found in jet planes and meets specifications AN-E-19 and MIL-T-5422.

Eight to twelve sub-miniature tubes plug into a high-thermal-conductivity magazine on top of a component space which is filled with a special thermo-setting compound after assembly. A removable shield cannister makes the thermal contact, allowing a total of 15 watts to be dissipated.

Input and output leads are brought to a standard 11 pin base, or multi-pin connector which permits the assembly to be plugged in like a tube. A fastener provides for mechanically securing the assembly to its socket.

A series of precision d-c analog computing amplifier circuits are also offered pre-packaged in the assembly. A typical circuit is a balanced direct coupled amplifier having nominal closed loop characteristics, such as: Output impedance one ohm, gain (open loop) 500, terminals for chopper type zero stabilization provided for zeroing to less than 3 millivolts referred to input. The size of an eight tube replaceable assembly of this type is $1\frac{7}{16} \times 1\frac{7}{16} \times 3\frac{7}{16}$.



Avion Instrument Corp.,
299 State Highway No. 17, Paramus, N. J.

CONTINUED ON PAGE 234

42 years of service to industry

DIE CASTINGS by ...

Stewart

small . . . large

. . . simple . . . intricate

In zinc, aluminum or magnesium

A DIVISION OF... STEWART SW WARNER

STEWART DIE CASTING

CHICAGO, ILL., 4535 FULLERTON AVE. . . . BRIDGEPORT, CONN., 275 WARREN ST.

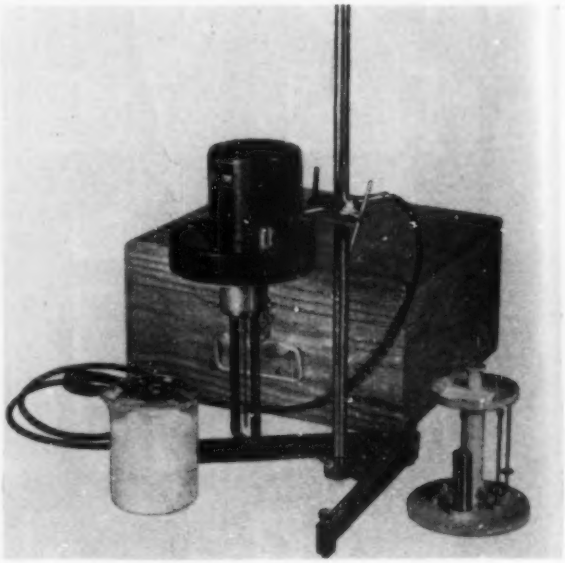
Accurate Wide Range Viscometers

With its 200 to 1 ratio of speeds starting at 0.3 rpm, the new eight-speed model LVT viscometer has application where wide ranges of viscosity may be encountered. When equipped with a UL adapter, an accessory designed to give special amplifying effects, the model LVT can measure any viscosity between 0.5 cps and 2,000,000 cps with great accuracy.

All models of the viscometers are portable and may be used in the laboratory, or plant. Each unit has a new bubble level attachment for correct leveling when making point-of-process determinations. Determinations are read directly in centipoises by inserting the instruments spindle in the material to be measured, and turning on the device, with the whole operation taking only a minute.

Each viscometer has a complete set of spindles, a spindle holder, and a carrying case that holds both the viscometer and spindle holder. Other viscometers include some 10 other single and four-speed models, available in speeds up to 600 rpm. Any standard model may be obtained with explosion-proof construction if necessary. This design adds little to the instrument's weight and bulk and does not affect its portability.

Brookfield Engineering Labs., Inc., Porter St., Stoughton, Mass.

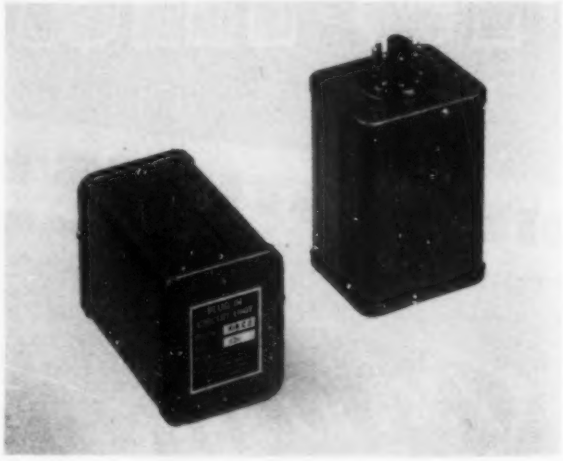


Potted Plug-In High-Gain Amplifier

A new miniature plug-in amplifier having high gain and relative independence of power supply voltage fluctuation is a compact unit, which measures approximately $1\frac{7}{8}$ x $2\frac{1}{4}$ x 3 in. and is potted in a steel case, to reduce microphonics. Specific characteristics include a maximum gain of 9000 and a flat frequency response from 2 to 1000 cycles per second. Power supply requirements consist of 600 ma, 6.3 v filament supply and 0.5 ma, 250 v plate supply. Maximum output voltage is 20 volts. Output impedance is 5000 ohms. Input impedance is 5 megohms. Input range is 50 microvolts to 2 millivolts rms (a-c on filaments).

Applications of the new amplifier include wide-range integrating circuits, in which integration is obtained by a stabilizing of the negative feedback circuit. Because of its single-stage characteristics, the amplifier will accept a large amount of negative feedback without instability.

Engineering Research Associates, Inc., 1902 West Minnehaha Ave., St. Paul 4, Minn.



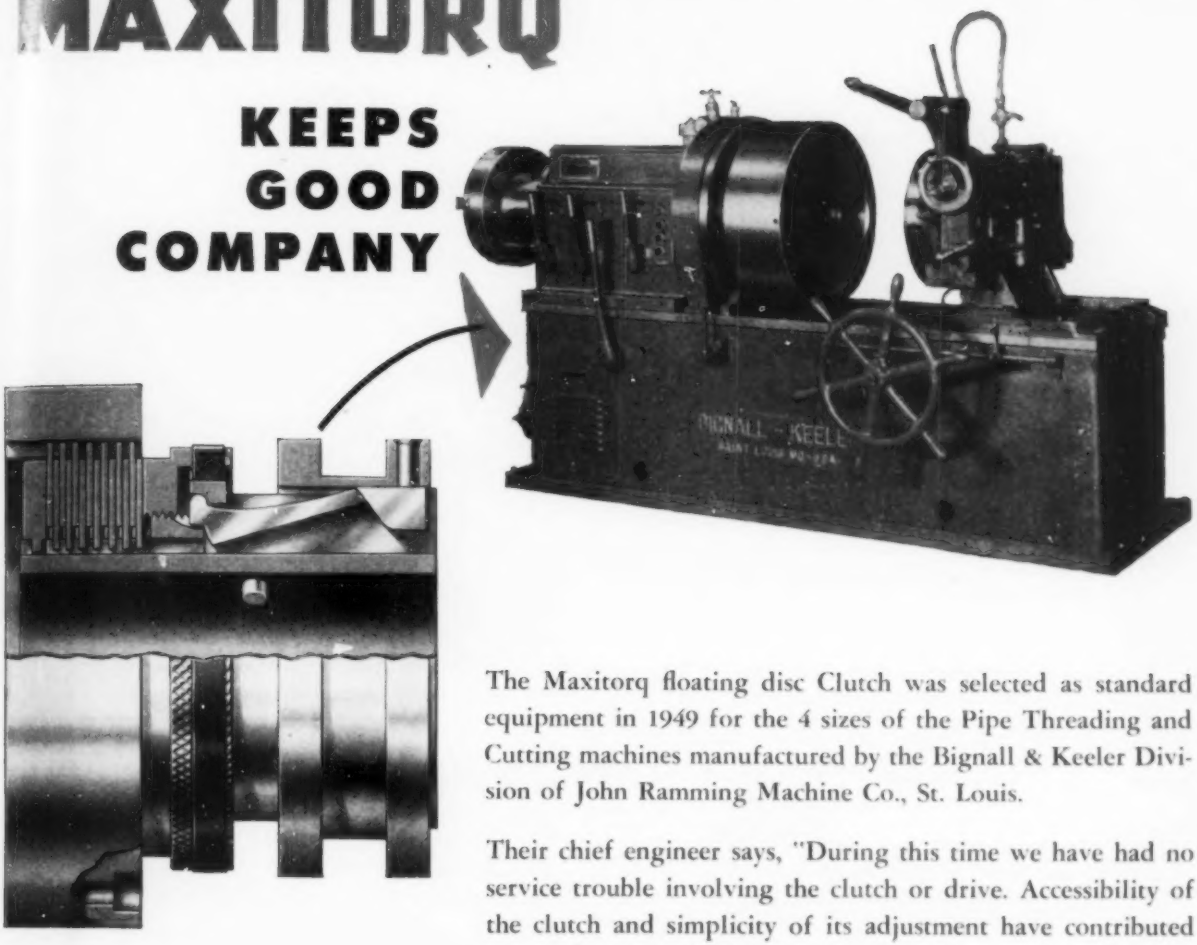
A plug-in line voltage ballast resistor, designed primarily to be plugged in between a TV set and an electric receptacle, is used in areas where line voltage tends to increase up to 140 volts. The unit operates on the ballast principle, whereby, as the voltage increases, the resistance increases, giving an increased drop across the resistance, and allowing a lower potential to be applied. Type TVA, 200 to 330 w; and type TVB, 300 to 375 watts. Clarostat Mfg. Co., Inc., Dover, N. H.

USED FOR FIELD SAMPLING and mineralogical research, a portable twinlite blacklite measures $1\frac{3}{4}$ in. high by 2 in. wide by $6\frac{1}{2}$ in. long. Complete with a 6 ft. cord and plug which plugs into a two battery (45 volt B) carrying case, the hand unit has two 4 watt blacklite lamps, and peaks at 3,600 angstrom range. Both units have upright chrome reflectors. The hand set may be plugged into any 110 v, 60 cycle line. Norco Mfg. Co., 392 Bleecker St., New York 14, N. Y.

CONTINUED ON PAGE 236

MAXITORQ

KEEPS GOOD COMPANY



The Maxitorq floating disc Clutch was selected as standard equipment in 1949 for the 4 sizes of the Pipe Threading and Cutting machines manufactured by the Bignall & Keeler Division of John Ramming Machine Co., St. Louis.

Their chief engineer says, "During this time we have had no service trouble involving the clutch or drive. Accessibility of the clutch and simplicity of its adjustment have contributed to a most successful design."

Maxitorq engineers are always pleased to see an application such as this, where it is possible to adjust or replace the clutch without tearing down the machine. One of our design objectives is to get more machine builders to adopt this policy. Maxitorq, however, gives top performance wherever it is installed.

If you require smooth, reliable power transmission within the Maxitorq range (8 sizes from fractional to 15 H.P. at 100 r.p.m.) single or double, wet or dry . . . ask our engineers for recommendations. Design is compact, streamlined . . . completely assembled on body and shipped ready to slip onto a shaft. Separator Springs prevent drag, abrasion, and heating in neutral . . . all assembly, adjustment and take-apart are manual operations.

SEND FOR CATALOG NO. PE9.

THE CARLYLE JOHNSON MACHINE COMPANY
MANCHESTER • CONNECTICUT

5 CJ 52

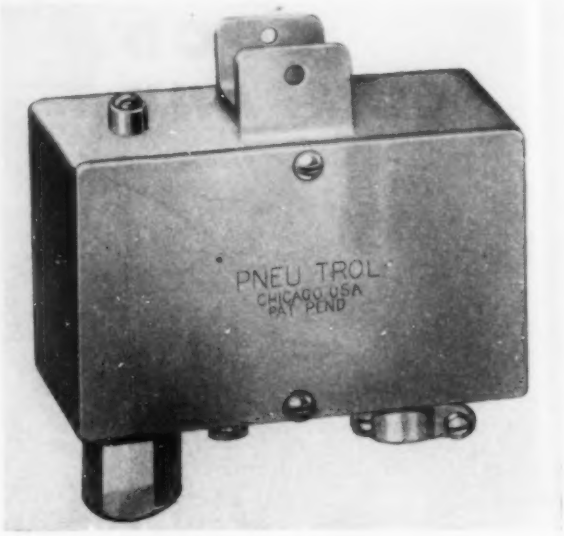
Time Control of Cylinder Powered Machines

A recently introduced time delay switch has a wide variety of thrust linkages for either right or left downthrust, upthrust, or horizontal thrust actuation. The new switch increases the application and widens the use of air and hydraulic cylinder power in controlling machine movements by providing controlled time dwell at positive stops on either end of the cylinder movement. These time delay switches are said to offer a practical hydraulic method and low cost answer for accurately controlled time dwell, and are making possible automatic control of many machine and tool motions.

The new switches can be furnished to dwell in any 20 to 1 ratio from a minimum of ¼ sec to a maximum of 60 seconds. Changing of the liquid viscosity in the dashpot will give variation in the dwell ratios. Time delay adjustments within the 20 to 1 ratio are quickly made by turning the knurled adjusting screw on the switch housing.

The switch is also available in explosion proof and vapor sealed types. Compact in size, the time delay switches can be mounted at the cylinder where their small size offers no obstruction or interference to machine movement.

Pneu-Trol Devices, Inc., 1438 N. Keating Ave., Chicago, Ill.



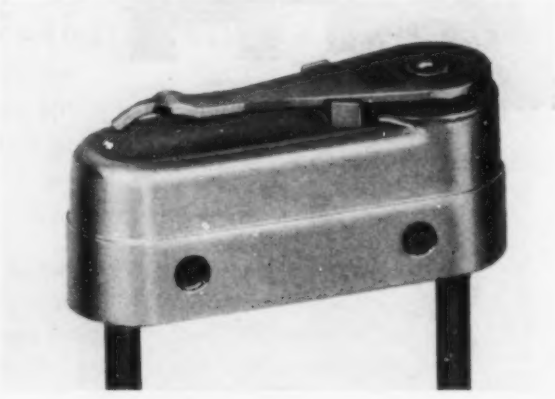
Waterproof, Precision, Snap-action Switch

A waterproof, snap-action switch having potted, waterproof terminal leads, and a hermetically sealed contact chamber, makes possible the use of precision, snap-action switches at locations which are subject to immersion, and will be of particular value for applications on marine and amphibious craft. The waterproof, hermetically sealed character of this switch also makes its use possible in aircraft, mobile, and marine applications where moisture, dirt, and other conditions could damage, reduce the capacity, or short the terminals of other switches.

The waterproof leads, which are connected to the terminals of this switch, are potted in a high-dielectric plastic which completely seals the terminals and leads. These type 4HS switches are available with leads of any required length, and can be supplied with waterproof couplings.

The metal case of this switch is sealed at the top by a metal diaphragm, through which the external actuating lever operates. The contact chamber is filled with an inert gas under pressure and sealed. All parts of the switch, including the waterproof embedment, are constructed to resist damage in applications where strength is essential.

The electrical rating of the 4HS switch is: 10 amp inductive load, or 25 amp resistive load, 28 volts d-c; 1 amp inductive or resistive load, 125 volts a-c. This switch can be had with single-pole, single-throw, or double throw.



Characteristics: Operating force, 16 oz, ±6 oz; release, force, 4 oz, min.; pretravel, 0.065 in., max; differential travel, 0.020 in., max; overtravel, 0.010 in., min; contact break distance, 0.036 in., minimum.

Micro Switch, Freeport, Ill.

A NEW HEAVY-DUTY UNIVERSAL JOINT has a 6 in. hub dia, and a length of 15½ in. (single joint) and 25 in. (double joint). Weight of the single joint is 98 lb and of the double joint, 155 pounds. The joint has forks cast of alloy steel. Curtis Universal Joint Co., Springfield, Mass.

ELECTRICAL INSULATION made of fiberglas coated with silicon rubber, offers high heat resistance, and retards fraying. Dielectric strengths in different NEMA grades from 1,500 to 7,000 volts; temperature range from —90 to plus 400 F. Bentley, Harris Mfg. Co., Conshohocken, Pa.

A LAMINATED PLASTIC GROMMET that springs out and holds tight is mechanically and dielectrically strong, resistant to high heat, hot oil, and excessive humidity. The ring is grooved, beveled, and a diagonal slit made to release the tension.—Continental-Diamond-Fiber Company, Newark, Del.

CONTINUED ON PAGE 238

1,300,000 CASTINGS FROM THIS DIE-

Since Sept. 1947

CASE HISTORIES FROM MT. VERNON FILES

Here at Mount Vernon, we are proud of our long-lived dies that "stand the gaff", exceed normal life expectancy, despite the severe punishment of continuous operation. The one pictured has duplicated the casting shown more than 1,300,000 times—and this die is still in use.

Die casting affords two outstanding production economies: (1) rapid production; (2) reduced machining and finishing.

Both advantages are fundamental factors in establishing lower unit costs. But the degree to which savings may be realized depends upon the quality of the workmanship in making the dies and the care with which they are used. Dies that retain their accuracy for longer periods—yield clean, flawless castings day in and day out—quickly write off initial costs, and reduce ultimate costs appreciably.

If you have not already profited by the economies to be gained from die casting, consult with us. We are confident that, with our comprehensive experience, skills and modern facilities, we can show you the way to increased output at lower cost.

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DIE CASTING CORP.
MT VERNON, NEW YORK

Produced for The Apex Electrical Mfg. Co.
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LOW COST
IRIDITE®
FINISHES

for zinc, cadmium, aluminum and cuprous metals

provide corrosion resistance
paint base
choice of appearance

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combine to make Iridite the most economical chromate finish you can buy. Many Iridite chemicals are packed in powder form, thus can be shipped to you in steel pails at freight savings of up to 75%! Pails take less storage space, are easier to handle, eliminate carboys, need not be returned.

WHY NOT TEST IRIDITE ON YOUR PRODUCTS? Write for literature and send samples for free test processing. See "Plating Supplies" in your classified telephone directory or write direct.

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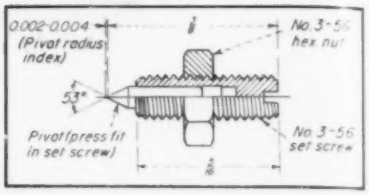
Manufacturers of Iridite Finishes
for Corrosion Protection and Paint Systems on Non-Ferrous Metals; ARP Plating Brighteners.
West Coast Licensee: L. H. HUTCHER COMPANY

Pivot Bearing Assembly

An instrument type pivot bearing assembly, consisting of a hardened and polished steel pivot mounted in a 3-56 set screw with a hex nut for locking this adjustable assembly in position is useful where a low friction strong assembly is necessary either with a jewel,



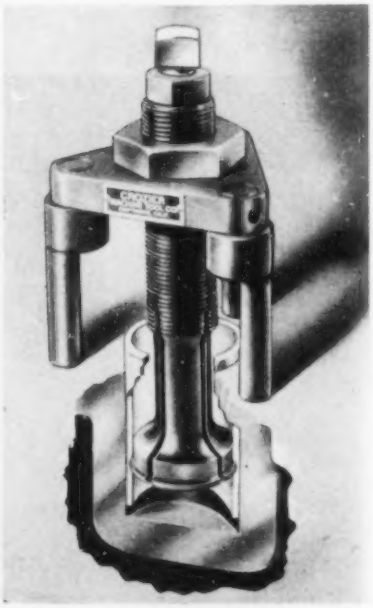
a coined vee, or a chanferred hole in a shaft. The pivot is made of hard close grained steel, heat treated and polished to a metallographic finish. The pivot has a PRI of 0.002 in. to 0.004 in. with a 53 deg cone angle. The pivot set screw is of mild steel with a precision rolled thread albayloy plated to prevent corrosion and improve appearance. The nut is also albayloy plated, and is used with a $\frac{3}{16}$ in. open end wrench to lock the adjustment.

Welton E. Johnson Engineering Co., Summit, N. J.

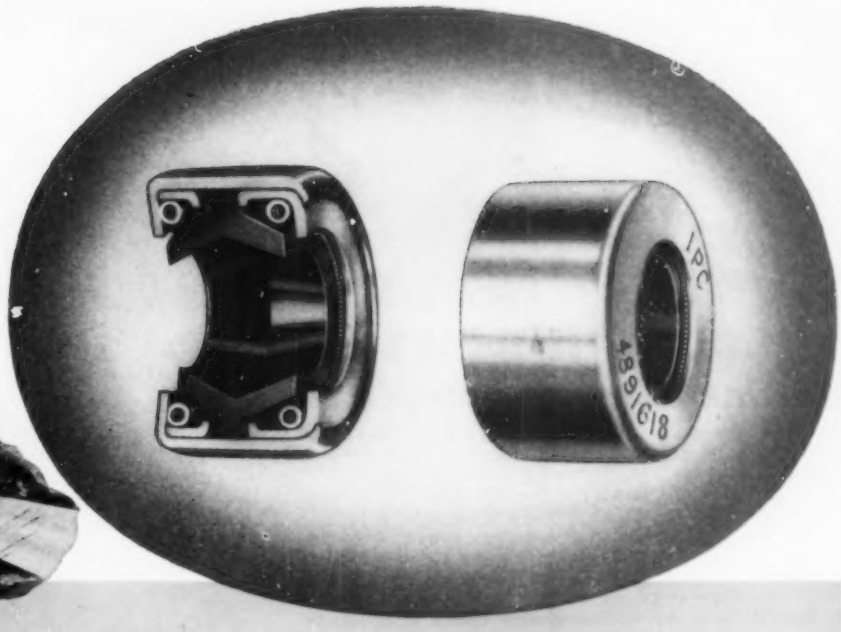
New Bushing and Bearing Extractor

A bushing and bearing extractor for blind holes, is claimed by its manufacturers to save up to 75 percent of the time in extracting bushings, bearings, sleeves, liners, roller bearing cups, and races of magnet type bearings.

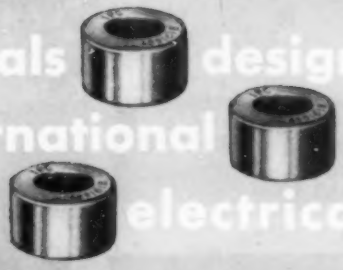
The new extractor consists of eight



the water has no place to go—*but out!*



These 3 seals designed and made by G&K-International keep the water out of this electrical throw switch



Courtesy Joseph Pollak Corporation

FREE O-RING BOOKLET
16 pages of illustrations, application data and specification charts. Write for your copy.

The AR5 Ordnance Lighting Switch pictured here will make and break the circuits *under water*. Three separate throw type contact switch mechanisms are operated by three levers located on the outside of the case. Surrounding each lever shaft is a seal, specially designed to keep water from passing along the shaft.

As shown in the cut-away view, the sealing elements are synthetic rubber, precision-molded with two balanced lips, each tension tightened by garter springs to insure a uniformly secure grip — and housed in a steel casing. More than 70,000 of these seals have been furnished to this one manufacturer.

G&K-INTERNATIONAL is ready to work with your engineers in designing special applications or to supply standard packings types to JIC standards. Call upon us for your packings needs, in leather or synthetic rubbers.

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GRATON & KNIGHT COMPANY
Worcester 4, Mass.

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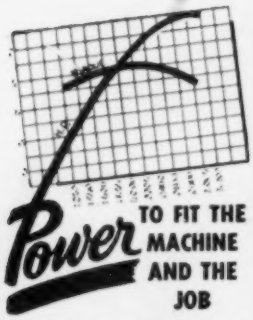
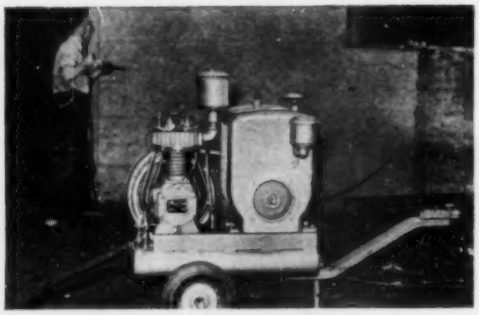
Bristol, New Hampshire

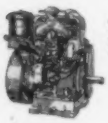


Power TO FIT THE MACHINE AND THE JOB



WISCONSIN-POWERED
Gardner-Denver Compressor

4-cycle Single Cyl. 3 to 9 hp.



4-cycle 2-Cyl. 7 to 13 hp.

V-type 4-Cyl. 15 to 30 hp.

This Model TP0493LE Portable Compressor, made by Gardner-Denver Co., Quincy, Ill., is supplying air for the operation of a Model S17 Utility Drill, engaged in a plant maintenance job. Complete power reliance is placed on the Model TF 2-cylinder Wisconsin Heavy-Duty Air-Cooled Engine.

More and more builders of engine-driven equipment are discovering, to the satisfaction of themselves and their customers, that you can't do better than to specify "Wisconsin Engines"... for dependable power to fit both the machine and the job.

Available in a complete power range from 3 to 30 hp., in 4-cycle single cylinder, 2-cylinder and V-type 4-cylinder models, Wisconsin Air-Cooled Engines provide economical power, without waste, to meet the most exacting requirements. Look into them for your use.

WISCONSIN MOTOR CORPORATION
World's Largest Builders of Heavy-Duty Air-Cooled Engines
MILWAUKEE 46, WISCONSIN

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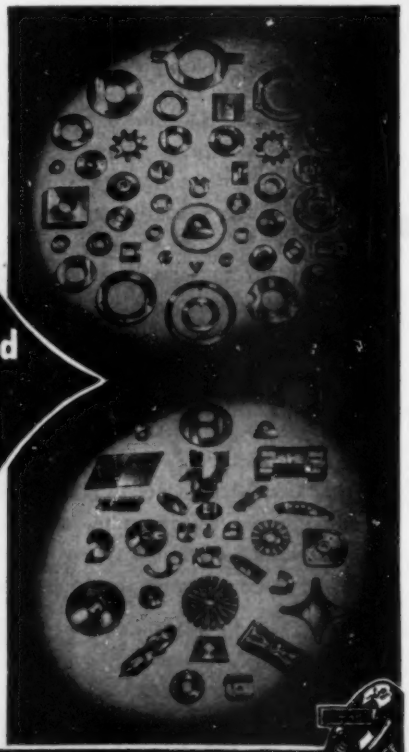

WASHERS and STAMPINGS

Standard and Special Washers, of every description, from every kind of material, any desired finish . . . designed for every purpose . . . utilizing more than 22,000 Sets of Dies.

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WROUGHT WASHER MFG. CO.
THE WORLD'S LARGEST PRODUCER OF WASHERS
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threaded expanding arbors, a draw table with two sets of legs, short and long, adjustable as to distance from the work, and can handle any hole from ½ in. to 2 in. diameter. A maximum of 2½ in. may be drawn at one setting, and press fits of over five tons have been extracted with this unit. Because of its adjustability, this set eliminates the need of stocking many sizes of pulls, therefore reducing inventory.

Crozier Machine Tool Co., 648 N. Prairie Ave., Hawthorne, Calif.

Rubber, Bearing-Type Seal

A new positive, two-piece bearing-type seal to prevent oil leakage from rear main bearings of automotive engines replaces rope or wicking seals as well as incorporating a new technique in shaft sealing. Made of oil-resistant hycar rubber, it is precision molded into a lip-type seal on a half-circle U-channel metal band. By fitting two of these half-seals around the

crankshaft and tightening together, a positive oil seal is obtained.

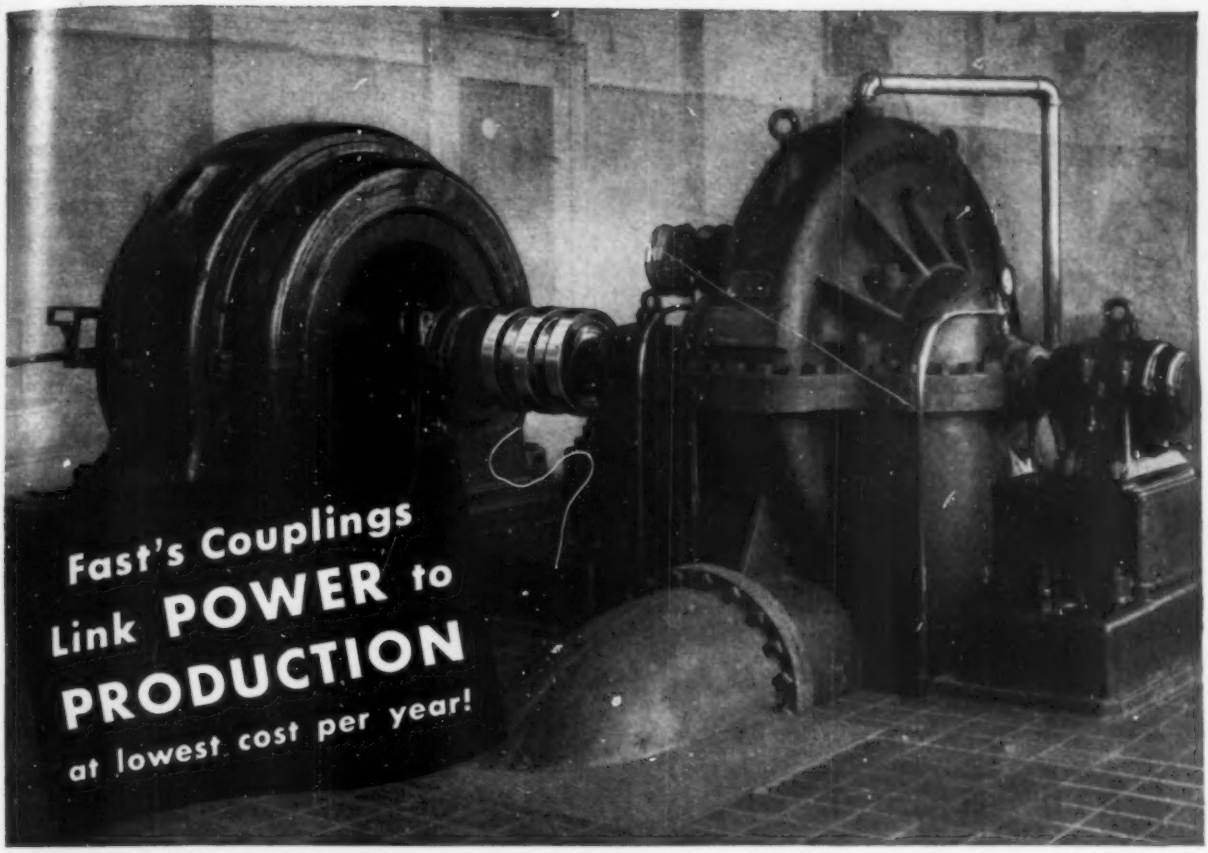
The metal base of the seal prevents distortion, and the rubber covering is molded to tolerances as close as the bearings and grind of the crankshaft.

Engine speeds up to 4,800 rpm are possible because the rubber resists the effects of temperature changes, abrasion, automotive oils and greases with added detergents, and engine acids.

Brummer Mfg. Co., 1320 McKinley St., Chicago Heights, Ill.

Power Supply For Large D-C Motors

A complete, self-contained all-purpose industrial selenium rectifier, measuring 26 in. x 40 in. x 65 in. high, operates from standard 3 phase a-c power lines, and turns out 230 v of d-c with sufficient capacity to run large d-c motors up to 25 hp, or energize electro-magnets and other d-c equipment.



FAST'S Couplings usually outlast the equipment they connect!

ACTUAL cases on record show many Fast's Couplings are still in service after as much as 30 years of continuous operation! Time and time again, equipment has been replaced while the original Fast's Coupling remained on the job.

To you, these records of dependable, trouble-free service mean freedom from costly coupling failures when you specify Fast's. And they mean Fast's cost you far less to own and operate . . . because their cost can be amortized over long years of dependable performance.

For full details on how Fast's Couplings and Koppers Engineering Service can help you, write today for a free copy of our catalog to: KOPPERS COMPANY, INC., *Fast's Coupling Dept.*, 239 Scott St., Baltimore 3, Maryland.

Here's How FAST'S Save You Money

Free Service—Koppers free engineering service assures you the right coupling for the job.

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FAST'S®
THE ORIGINAL
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Gentlemen: Send me Fast's Catalog which gives detailed descriptions, engineering drawings, capacity tables and photographs.

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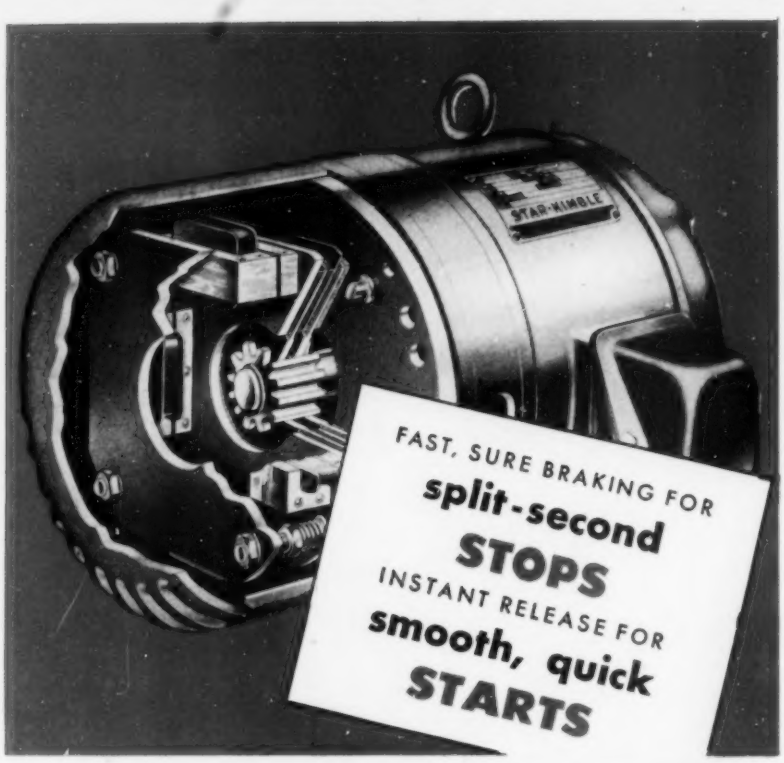


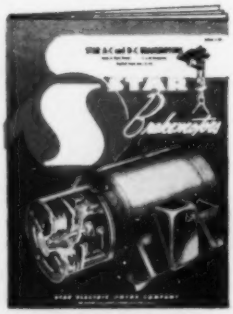
with STAR-KIMBLE BRAKEMOTORS

Where start-and-stop cycles are toughest, you'll find Star Brakemotors on the job, hour after hour, day after day!

The extra-large braking area of Star-Kimble Brakemotors assures quick *stopping*, positive *holding* of the load—gives long service life with little maintenance. Small air gap between electromagnets and brake disc results in extremely fast *release*—allows motor to start smoothly, without friction drag. *Other features:*

Brake discs mounted close to motor for low wear and strain on shaft and bearings. Magnets mounted away from motor for cool operation. Quick, simple adjustment of braking torque. Automatic re-set hand release—an exclusive, patented Star-Kimble feature.

Remember . . . a Star-Kimble Brakemotor is a compact, integral unit—motor and brake *built* together to *work* together. Each Star-Kimble Brakemotor is designed for specific service requirements—by the company that pioneered disc brakemotors and has applied them successfully, for more than 25 years.



Want to know how Star-Kimble Brakemotors work—what torque and motor ratings are available? Write for free Bulletin B-501-A.

STAR-KIMBLE

MOTOR DIVISION OF
[illegible] PRINTING PRESS & MANUFACTURING CO.

211 Bloomfield Avenue Bloomfield, New Jersey

The rectifier has: no moving parts to wear or require attention, no noise, and long life; no tubes or other perishable parts; over-load and surge capacity up to 600 percent of normal rating; low stand-by power consumption and high operating efficiency, approx 80 percent; instant operation, no time lag or warm-up period required.

Mellaphone Electronic Rectifier Co., Inc., Rochester 2, N. Y.

Alkaline Tin-Lead Stripper

A new alkaline chemical for the rapid dissolving of tin, lead, tin-lead electrodeposits, heavy solder, and hot dipped coatings will not attack base metals, such as copper, brass, bronze, steel, and stainless steels. Used in water in a concentration of one lb/gal., it is heated to from 160 to 180 F.

The stripping action on bath tin and lead is fast, and thicknesses of 0.005 in. to 0.010 in. are removed in one hour. When the time required for stripping increases by about 25 percent, additions of 8 oz/gal. of chemical should be made. There is a limit to the number of additions that can be made because the bath will build up in lead, retarding stripping action.

Phase Sequence Relay

A phase sequence relay recently introduced is said to give positive phase protection to all types of polyphase rotating machinery, which might function improperly, or be damaged by the application of reverse phase sequence, extremely low voltage, or single phase voltage.

The relay is compact and substantially constructed for continuous service. It operates on a simple principle,

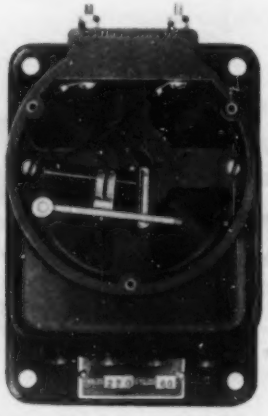


Fig. 1

23 MEEHANITE Castings in this HiDUTY Lift Truck

TRANSITIER Truck Co., Portland, Oregon, specify 23 important cast components in their line of HiDuty Lift Trucks (Fig. 1) in Meehanite metal. The importance of these parts is further emphasized by the fact that in recent months a number of them have been redesigned from original steel and bronze specifications. In addition to the ones shown, the following parts are Meehanite castings:

1. WHEEL SPACER
2. HYDRAULIC VALVE BODIES(2)*
3. CLUTCH DRIVEN PLATE
4. CLUTCH SUPPORT
5. TRANSMISSION CASE
6. BRAKE DRUM
7. WHEEL HUB(1)*
8. HYDRAULIC CYLINDER PACKING NUT (2)*

**In addition to similar parts shown.*

The design and specification of these components is a good example of the beneficial results of team work between a foundry manufacturing high property, high quality castings, and a manufacturer alert to the possibilities of incorporating dependability into his product through proper specification. The use of Meehanite castings provides a sure knowledge that both service and production requirements will be met regularly and repeatedly.

Write for our new Bulletin 35 "Meehanite Castings Serve all Industry."

Take *YOUR* Casting Problem To
A MEEHANITE FOUNDRY

American Brake Shoe Co.	Mahwah, New Jersey
The American Laundry Machinery Co.	Rochester, New York
Atlas Foundry Co.	Detroit, Michigan
Banner Iron Works	St. Louis, Missouri
Barnett Foundry & Machine Co.	Irvington, New Jersey
E. W. Bliss Co.	Hastings, Mich. and Toledo, O.
Builders Iron Foundry	Providence, Rhode Island
Compton Foundry	Compton, Calif.
Continental Gin Co.	Birmingham, Alabama
Crawford & Doherty Foundry Co.	Portland, Oregon
The Cooper-Bessemer Corp.	Mt. Vernon, Ohio and Grove City, Pa.
Empire Pattern & Foundry Co.	Tulsa, Oklahoma
Farrel-Birmingham Co., Inc.	Ansonia, Connecticut
Florence Pipe Foundry & Machine Co.	Florence, New Jersey
Fulton Foundry & Machine Co., Inc.	Cleveland, Ohio
General Foundry & Manufacturing Co.	Flint, Michigan
Greenlee Foundry Co.	Chicago, Illinois
The Hamilton Foundry & Machine Co.	Hamilton, Ohio
Hardinge Company, Inc.	New York, New York
Hardinge Manufacturing Co.	York, Pennsylvania
Johnstone Foundries, Inc.	Grove City, Pennsylvania
Kanawha Manufacturing Co.	Charleston, West Virginia
Lincoln Foundry Corp.	Los Angeles, California
E. Long Ltd.	Orillia, Ontario
Otis Elevator Co., Ltd.	Hamilton, Ontario
The Henry Perkins Co.	Bridgewater, Massachusetts
Pohlman Foundry Co., Inc.	Buffalo, New York
Rosedale Foundry & Machine Co.	Pittsburgh, Pennsylvania
Ross-Meehan Foundries	Chattanooga, Tennessee
Shenango-Penn Mold Co.	Dover, Ohio
Sonith Industries, Inc.	Indianapolis, Ind.
Standard Foundry Co.	Worcester, Massachusetts
The Stearns-Roger Manufacturing Co.	Denver, Colorado
Traylor Engineering & Mfg. Co.	Allentown, Pennsylvania
Valley Iron Works, Inc.	St. Paul, Minnesota
Warren Foundry & Pipe Corporation	Phillipsburg, New Jersey

"This advertisement sponsored by foundries listed above."

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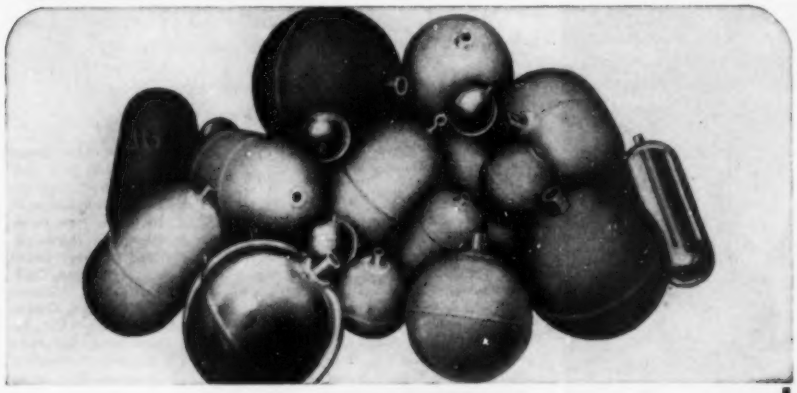

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FLOAT BULLETIN 650

Complete Data on Welded Floats; Diagrams, Tables, Formulae for Calculating Buoyancies

The booklet is a standard reference for specifiers of welded floats. Nicholson furnishes any type for external or internal pressures; in stainless steel, Monel, chromium, cadmium or copper-plated steel. Sizes, 2" to 14" diam., press. to 4800 lbs.; standard or special connections. Quick delivery on many sizes and shapes. Nicholson floats are standard with hundreds of manufacturers.

206 OREGON ST. WILKES-BARRE, PA.

and has no delicate parts to get out of adjustment. Power consumption is 5 watts per phase.

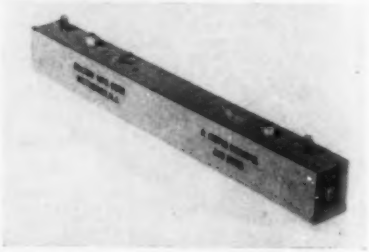
The relay will operate on either 2 or 3 phase a-c, and is made for all voltages and frequencies ordinarily encountered.

Shepard Elevator Co., 5000 *Brotherton Rd., Cincinnati 9, Ohio*

Low-Loss Delay Lines

New electrical delay lines for use in computors, radar, television, and other electronic applications where delays are required ranging up to 100 microseconds, feature low-loss, good temperature stability through the use of specially engineered temperature compensating capacitors, and small physical size.

The delay line shown in the illustration has the following characteristics: delay time, 1.1 microsec; rise time (from 10 to 90 percent of step function) 0.1 microsec; bandwith, 2.0 mc; attenuation, less than 1 db; characteristic impedance, 460 ohms; number of sections, 15; dimensions $\frac{3}{4}$ x $\frac{7}{8}$ x $8\frac{1}{8}$ in.; weight, 5 ounces.

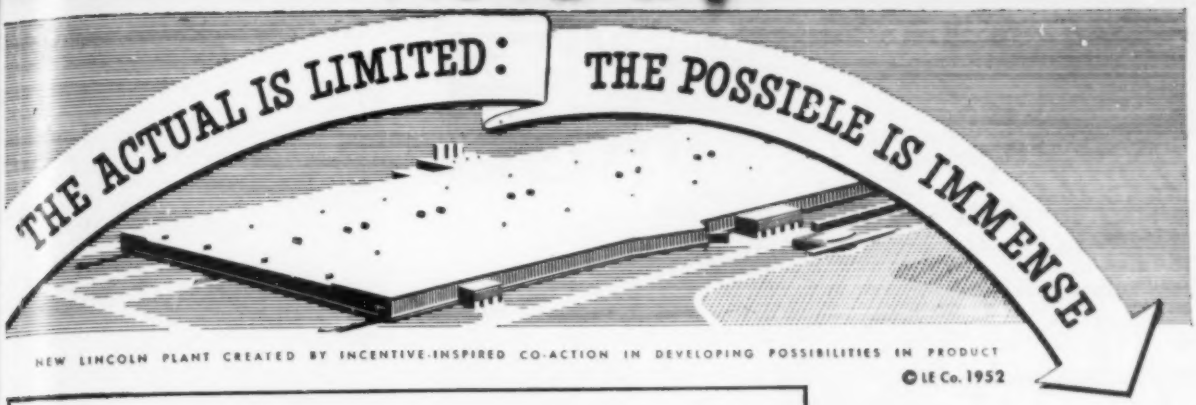


Gulton Mfg. Corp., 212 *Durham Ave., Metuchen, N. J.*

Two Gun Tube For Higher Accelerating Voltages

A two-gun multi-post accelerator band cathode ray tube originally designed for oscilloscopes requiring the high accelerating potential necessary for recording high-speed transient phenomena, now has application in the newer types of radar search equipment.

Designated as type 52HAP7, the new ETC tube is similar to RTMA Type 5SP7 except for being designed for operation at higher accelerating voltages. A maximum of 25,000 volts d-c can be applied to the final post accelerator anode. In addition, a new type aluminized screen is said to permit greater luminous efficiency in tubes



NEW LINCOLN PLANT CREATED BY INCENTIVE-INSPIRED CO-ACTION IN DEVELOPING POSSIBILITIES IN PRODUCT

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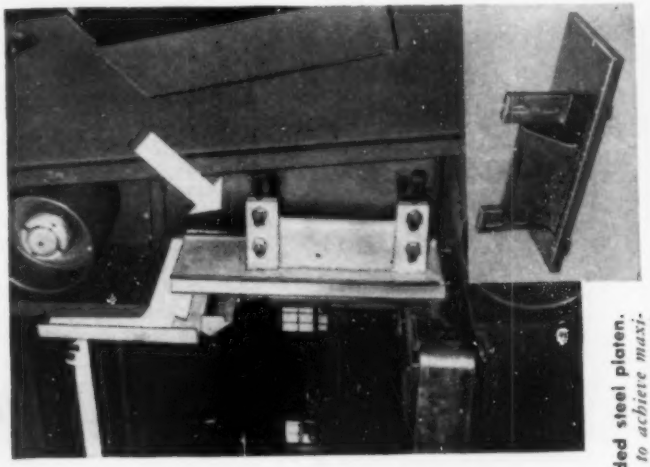
WELDED DESIGN INCREASES RIGIDITY WITHOUT INCREASING COST

By **Eric Hartmann,** Experimental Research Engineer
The Porter Cable Machine Co., Syracuse, New York



BY changing over the design of our belt platen support to welded steel construction, we have cut deflection over 90%. The former cast construction, (Fig. 1) would deflect from .017" to .020" under 400 pound table pressure. The present welded steel design deflects only .0015" to .002" ... 10% of its original value.

Since steel is 2½ times more rigid than gray iron, it was possible to develop a more efficient product design on the platen itself without changing the basic dimensions of the machine or without increasing costs. On machine tools like ours, rigidity is basically important as it directly affects ultimate accuracy and efficient operation of the equipment.

Fig. 3—Detail of Column *on Porter Cable BG-8 Grinder. Shows assembly of belt platen support governing the ultimate accuracy and efficiency of the machine.*

Inset: Rear view of welded steel platen. *Shows efficient use of steel to achieve maximum strength and rigidity per pound of metal.*

WELDED DESIGN ALWAYS SAVES STEEL AND LOWERS COST

Fig. 1—Former Design—*Belt platen support for grinder was originally a casting. Required machining operations to finish the front face and the mounting arms.*

Fig. 2—Present Design in Welded Steel—*Is simpler to fabricate than the original construction. Components are pre-machined prior to welded assembly to simplify manufacture.*

HERE'S HOW

Machine Design Sheets free on request. Designers and Engineers write on your letterhead to Dept. 38,

THE LINCOLN ELECTRIC COMPANY
Cleveland 17, Ohio

THE WORLD'S LARGEST MANUFACTURER OF ARC WELDING EQUIPME

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B BETTER PRODUCTS
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Michigan
Electric Resistance
WELDED
STEEL
TUBING

A Quality Product

ROUND
⅜" to 4" O. D. 9 to 22 gauge
SQUARE-RECTANGULAR
½" to 2" 20 gauge, 1" to 2¾",
14, 16, 18 gauge
Carbon 1010 to 1025

Michigan Tubing
has uniform strength, weight, ductility, I. D. and O. D., wall thickness, machinability, and weldability. It can be flanged, expanded, tapered, swaged, beaded, upset, flattened, forged, spun closed, fluted, and rolled. Available in a wide range of sizes, shapes and wall thicknesses, prefabricated by Michigan or formed and machined in your own plant.

Steering Jacket

Ready for the automobile assembly line is this vital volume produced tubular part of a major control unit.

Lower tube end is reduced to 2.260" O. D. x 10.525" long, held to close tolerance for assembly in line with body of base tube without machining. Upper end is reduced to 2.125" O. D. x 2.562" long, held on center line to extremely close decimal dimensions, with two perforations at tapered section. Michigan workmanship can always be depended upon to assure the exacting tolerances and part uniformity to keep customer assembly operations moving smoothly.

Michigan engineers will be pleased to work with you on an adaptation of welded steel tubing to help you make your product better at lower cost.

Consult us for engineering and technical help in the selection of tubing best suited to your needs.

Plus Fabricating of our own tubing Michigan is interested ONLY IN THE FABRICATION OF Stainless steel, copper, brass and aluminum tubing.

Michigan STEEL TUBE PRODUCTS CO.
THE OLDEST NAME IN ELECTRIC RESISTANCE WELDED STEEL TUBING

More than 35 Years in the Business
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FACTORIES: DETROIT, MICHIGAN—SHELBY, OHIO

DISTRIBUTORS: Steel Sales Corp., Detroit, Chicago, St. Louis, Milwaukee, Indianapolis and Minneapolis—Miller Steel Co., Inc., Hillside, N. J.—C. L. Hyland Co., Dayton, Ohio—Dirks & Company, Portland, Oregon—James J. Shannon, Milton, Mass.—Service Steel Co., Los Angeles, Calif.—Hugh Davis, Jr., Sewickley, Pa.—Strong, Carlisle & Hammond Co., Cleveland, Ohio—Globe Supply Co., Denver, Colorado—W. A. McMichaels Co., Upper Darby, Pa.—A. J. Fitzgibbons Co., Buffalo, N. Y.—Harry E. Clark & Co., Houston, Texas—J. B. Beaird Co., Inc., Shreveport, La.

designed to operate at accelerating voltages above 5,000 volts.

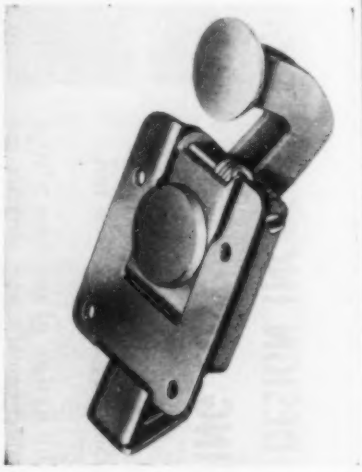
Under typical conditions with the final anode operating at 10,000 volts, the second anode potential maintained at 2,000 volts (with the intermediate accelerator anodes being fed from a series of 25 megohm bleeder sections) the focusing anode potential will be between 362 and 695 volts with control grid cutoff between —30 and —90 volts. The deflection factors D_1D_2 are 102 to 154 volts d-c, and D_3 D_4 are 84 to 126 volts d-c.

Electronic Tube Corp.
1200 E. Mermaid Lane, Philadelphia 19, Pa.

Push Button Flush Latch

Designated as H-4100, this new latch is specially designed for a variety of commercial, industrial, aircraft, marine, and transportation applications. Its only exposed parts are the recessed completely flush, circular trigger button and close button.

Finger-tip pressure opens the latch. As the forward button is depressed,



the rear button raises, making a sturdy grip for opening the door.

The latch is available in stainless steel, cadmium plated cold rolled steel, or aluminum alloy, and weighs 0.7 to 2 ounces, according to the material.

Hartwell Co., 9035 Venice Blvd., Los Angeles 34, Calif.

Microsecond Pulse Transformer

The new type PT-1 pulse transformer is a versatile unit for use in the microsecond and fractional microsecond ranges. Compactly built in an octal tube base, it has six sections of wind-

ings, of which two pairs are connected in series and the other two sections individually connected to base pins. It is useful in blocking oscillators and other pulse circuits.

Specifications: windings, No. 36 wire, 50 turns each section; connections, 1 and 8, 2 and 7, two sections in series, 3 and 4, 5 and 6, single section; dia. 1.372 in. max; height, 1.107 in. max; overall height, 1.657 in. maximum.

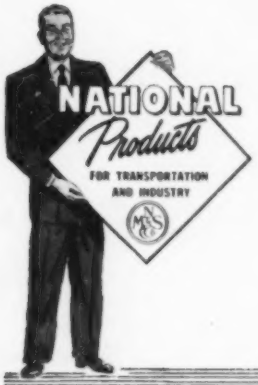
Berkshire Labs., 510 Beaver Pond Rd., Lincoln, Mass.

A BLEND OF SPECIAL SOLID WAXES put up in stick form for use in certain types of metal-working operations is said to provide a durable, clean lubrication for metal sanding, metal sawing, pipe cutting and threading, drilling, tapping, grinding and flush riveting. Lubrication with Stik-Wax, is said to extend the life of saws, drills and cutting tools as well as sanding and grinding surfaces. Wax lubrication also results in a better finish on the worked pieces. Burrs are eliminated and a smoother finish is possible when grinding or sanding metal surfaces. S. C. Johnson & Co., Inc., Industrial Products Dept., Racine, Wis.

WEDGELOCK SUPPORTS, a new type of cable support and conduit seals, are being used for supports that allow for extensions, and for horizontal installations. The device not only supports the cable, but is compound-filled to prevent water flowing down the cables into the conduit. For outdoor use the fitting has an aluminum alloy body which for single-phase circuits is nonmagnetic. The fitting has a wedge insert of a laminated phenolic material, of high tensile and dielectric strengths. The Adalet Mfg. Co., 14300 Lorain Ave., Cleveland 11, Ohio.

Castings by National

selected for Quality and Dependability



Products bearing these familiar trademarks have all established enviable reputations for quality and dependability. And to guard product reputations, these manufacturers *continue* to specify castings by National —one of the Nation's largest founders.

National's unparalleled experience in producing malleable, heat-treated malleable, and steel castings is at your disposal. Sales offices and engineering facilities are located at all five strategically located plants.

PLANTS LOCATED IN Sharon, Pa., Cleveland 6, Ohio, Indianapolis 6, Ind., Melrose Park, Ill., and Chicago 50, Ill.

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A 16mm technicolor film. Narrated by Edwin C. Hill, this 27-minute film tells how malleable iron is made . . . tested . . . used . . . how its production economy, ductility, machinability, toughness will give you a better finished product. Available for group showings.

NATIONAL Products FOR TRANSPORTATION AND INDUSTRY Est. 1868

NATIONAL MALLEABLE and STEEL CASTINGS COMPANY
CLEVELAND 6, OHIO

the A-B-C of M-S-T

A ALWAYS MAKES POSSIBLE
B BETTER PRODUCTS
C AT LOWER COST

Michigan
Electric Resistance
WELDED
STEEL
TUBING

ROUND
⅜" to 4" O. D. 9 to 22 gauge
SQUARE-RECTANGULAR
½" to 2" 20 gauge, 1" to 2¾",
14, 16, 18 gauge
Carbon 1010 to 1025

Michigan Tubing
has uniform strength, weight, ductility, I. D. and O. D., wall thickness, machinability, and weldability. It can be flanged, expanded, tapered, swaged, beaded, upset, flattened, forged, spun closed, fluted, and rolled. Available in a wide range of sizes, shapes and wall thicknesses, prefabricated by Michigan or formed and machined in your own plant.

Plus Fabricating of our own tubin
FABRICATION OF Stainless steel,

Michigan ELECTRIC RES ST
THE OLDEST NAME IN

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DISTRIBUTORS: Steel Sales Corp., Detroit, Chicago, St. Louis, Milwaukee, Indianapolis and Minneapolis —Miller Steel Co., Inc., Hillside, N. J.—C. L. Hyland Co., Dayton, Ohio—Dirks & Company, Portland, Oregon —James J. Shannon, Milton, Mass.—Service Steel Co., Los Angeles, Calif.—Hugh Davis, Jr., Sewickley, Pa.— Strong, Carlisle & Hammond Co., Cleveland, Ohio—Globe Supply Co., Denver, Colorado—W. A. McMichaels Co., Upper Darby, Pa.—A. J. Fitzgibbons Co., Buffalo, N. Y.—Harry E. Clark & Co., Houston, Texas—J. B. Beaird Co., Inc., Shreveport, La.

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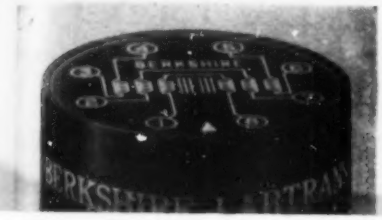

Castings by National

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d Dependability

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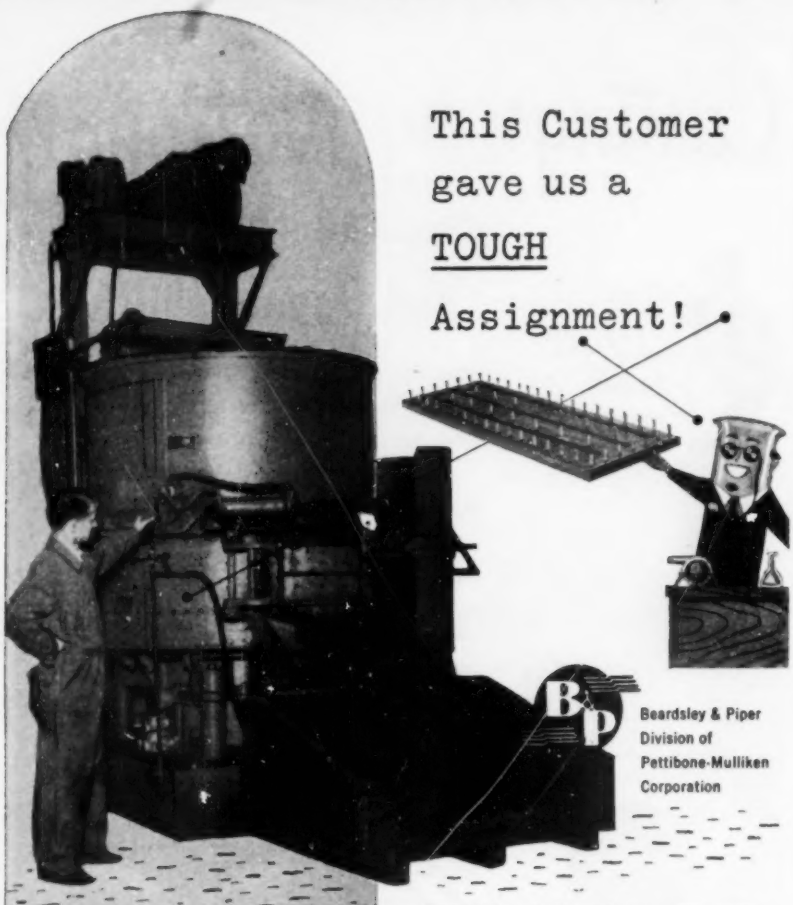
NATIONAL Products

NATIONAL MALLEABLE and STEEL CASTINGS COMPANY
CLEVELAND 6, OHIO
Est. 1868

of high tensile and dielectric strengths. The Adalet Mfg. Co., 14300 Lorain Ave., Cleveland 11, Ohio.



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MEETINGS

September 8-10

NATIONAL STANDARDIZATION CONFERENCE, Sponsored by American Standards Association—Museum of Sciences and Industry, Chicago.

Sept 8-11

AMERICAN SOCIETY OF MECHANICAL ENGINEERS—Fall Meeting, Sheraton Hotel, Chicago, Ill.

September 8-12

INSTRUMENT SOCIETY OF AMERICA—Seventh National Instrument Conference and Exhibit, Cleveland Auditorium, Cleveland, Ohio.

September 9-11

SOCIETY OF AUTOMOTIVE ENGINEERS — Tractor Meeting. Hotel Schroeder, Milwaukee, Wis.

September 11-14

PACKAGING MACHINERY MANUFACTURERS INSTITUTE—Annual Meeting. The Homestead, Hot Springs, Va.

September 24-26

AMERICAN HOT DIP GALVANIZERS ASSOCIATION—Semi-Annual Meeting, Greenbrier Hotel, White Sulphur Springs, West Virginia.

September 29-October 1

NATIONAL ELECTRONICS CONFERENCE—Eighth Annual Conference, Sherman Hotel, Chicago, Ill.

September 30-October 3

ASSOCIATION OF IRON AND STEEL ENGINEERS—Annual Convention and Iron and Steel Exposition, Cleveland Public Auditorium, Cleveland, Ohio.

October 1-3

NATIONAL ASSOCIATION OF CORROSION ENGINEERS—South Central Region Conference, Jung Hotel, New Orleans, La.

October 10

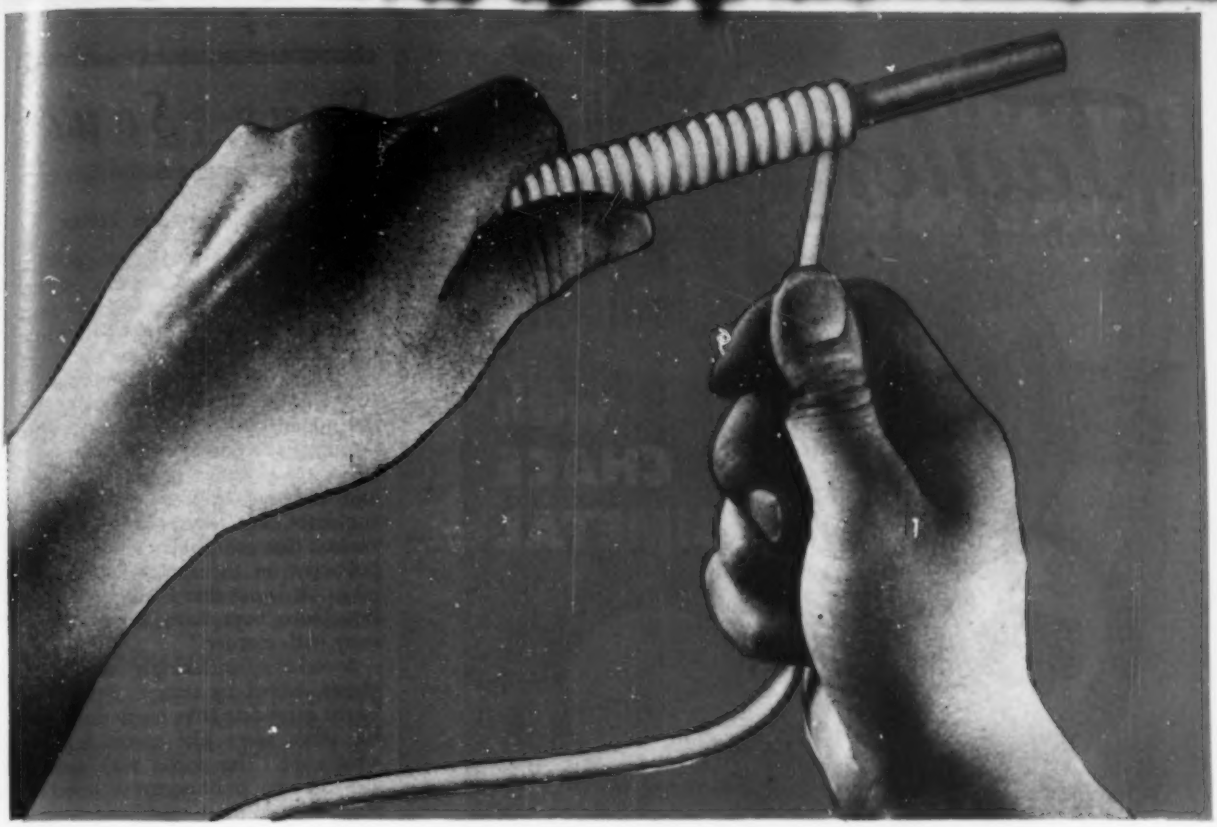
NATIONAL NOISE ABATEMENT SYMPOSIUM—Armour Research Foundation of Illinois Institute of Technology, Chicago, Ill.

October 20-24

NATIONAL METAL EXPOSITION AND CONGRESS—Sponsored by the American Society for Metals, Convention Hall, Philadelphia, Pa.

October 21-29

ROYAL NETHERLANDS INDUSTRIES FAIR—Chemical and Food Processing Machinery, Rotterdam, Holland.



Now . . . an extremely flexible high-temperature tubing . . . IRVINGTON Silicone Rubber-Coated Fiberglas*

If you need a *flexible* insulating tubing that meets Class "H" specifications—and particularly if you need it *now*—look into this new Irvington product!

With the introduction of Silicone *Rubber*-Coated Fiberglas Tubing, Irvington offers to the electrical industry a product that, like the resin-coated type, meets all NEMA Class "H" requirements. In addition, this new tubing has the advantage of extreme flexibility. Its white color is a plus wherever appearance is a factor.

AND . . . Irvington Silicone Rubber-Coated Fiberglas Tubing is available for immediate delivery!

Get the full story—just mail the coupon for technical data sheet.

*T.M. Reg. U. S. Pat. Off. by Owens-Corning Fiberglas Corp.

Send this convenient coupon now

Irvington

VARNISH & INSULATOR COMPANY

Irvington 11, New Jersey

Plants: Irvington, N. J.; El Monte, Calif.; Hamilton, Ontario, Canada

PE-9/52

Irvington Varnish & Insulator Co.
10 Argyle Terrace, Irvington 11, N. J.

Gentlemen:
Please send me technical data sheet on Irvington Silicone Rubber-Coated Fiberglas Insulating Tubing.

Name..... Title.....

Company.....

Street.....

City..... Zone..... State.....

For Further Information, Consult pages 92-93 in the 1951-1952 Electronics Buyers' Guide

Taylor puts MEMORY in Temperature Indication with CHACE BIMETAL

Product of:
Taylor Instrument Companies
Rochester, New York

This handsome three-in-one Taylor Remo-Set thermometer makes you the weather expert in your neighborhood. The window dial indicates the present temperature as well as the highest and lowest temperature since last resetting. It is easy to read, highly accurate and attractively styled in weatherproof beige plastic case, with large ivory numerals and graduations on green dial. The reliability of this Taylor instrument is largely dependent upon the actuating element of Chace Thermostatic Bimetal.

A precision wound coil is anchored to a center stud, the present temperature pointer being attached to the outer end. Rising and falling temperatures cause the pointer to move the high and low indicators to the temperature extremes where they are locked in position, under hair-spring tension, by a ratchet mechanism. The maximum temperature indicators are pneumatically reset to the present temperature by a yoke, operated by a rubber diaphragm, and connected by a vinylite plastic tubing to a push button indoors.

Chace Thermostatic Bimetal is manufactured in 29 types, in strips, coils, random long lengths and welded or brazed sub-assemblies. We also provide specialized tooling necessary to fabricate bimetal elements to customer designs. Before proceeding with your next design, we invite you to consult our Application Engineers, recognized authorities on temperature responsive devices—or write today for a copy of our new 32-page booklet, "Successful Applications of Chace Thermostatic Bimetal," containing engineering data.

W. M. CHACE CO.
Thermostatic Bimetal
1607 BEARD AVE., DETROIT 9, MICH.

Sans, Souci

Ad Libbing by the Editor

Now that the two great political conventions are over, we can go back to swimming, golf, sweating and swatting mosquitos. And of course we have time for reminiscing about the greatest quadrennial shows on earth, the two great political conventions for the nomination of candidates for the presidential election.

For many years I have been griping and crabbing because scientists and engineers have never produced an invention that contributes to putting the politician on the spot where he belongs. It is not that I hate politicians. But those boys have been "getting away with murder."

Speeches painstakingly written by ghosts, edited by stooges and signed by the candidate have made candidates for office seem like something that what ain't. The public with nothing else to go on, must accept or reject the written word as it reads and sounds. But now it is all different. Television, even with all the faking that accompanies it, shows the man as he is. Since the two circuses in Chicago many a hitherto party big-wig has fallen mightily in public esteem.

Public opinion created by speech and action heard and seen on television will force many changes in the presidential convention procedures and the behavior of candidates. Hired professional talent, like the paid mourners at a heathen funeral, will be out. The circus performance wherein both amateur and professional talent goes off on a binge of supposedly soul stirring histrionics and cheese cake is not compatible with the purposes of a convention to nominate a president of the U. S. A. Ill mannered behavior and arrogance on the part of individuals who consider themselves great political leaders topples them off their throne when the all-revealing television camera exposes them to public view. Television is science's greatest contribution to better government because it presents candidates and office holders more revealingly.

Research for Rescue or Ruin

In a recent speech Mr. Herbert Hoover, whom I greatly admire, said in effect that the only hope of getting out of the present economic predicament was technological advancement. If science and engineering could quickly produce many new amazing machines and processes that would

greatly increase productivity it might be possible for the U. S. to produce fast enough to satisfy the insatiable appetite of the world for food and manufactured goods.

On the basis of Mr. Hoover's statement many more politicians might get the idea that the federal government should go even more all out for industrial research and thereby save the world. The fact is that the U. S. Federal Government is already spending more than half the total amount of money spent in the U. S. A. for research. And thereby hangs a tale.

With 22 separate government agencies spending 1.6 billion dollars a year for research work that is spread amo 1,500 industrial organizations, many government laboratories and 500 colleges, it is a safe bet that a goodly portion of the money spent is wasted.

The Unpayable Payoff

The greatest national loss created by the mad scramble of our politicians to get control of scientific research is its effect upon our universities. The basic reason for the existence of a university is to serve as an institution for learning. Over the past decades colleges and universities have been getting further and further away from this concept. Forced by increased operating costs, lower income from endowments and war-time demands, colleges and universities have been looking more and more to government handouts in various forms in order to be able to balance their budgets.

Today the very atmosphere on many a college campus has changed from the air of an institution of learning to the buzzing of a research factory. What was once in the forefront of engineering schools is now the greatest research mill in the world with more than $10,000,000 in government research contracts. Where once the product was engineers today it is research reports and commercial achievements. Relatively fewer professors are teaching, many more of the institute's employees are technicians and mechanics and the headlines of the annual report relate more to turnover of research dollars. Teaching has become even less than a by-product. Even basic research to increase the fund knowledge is side tracked in favor of the glamour and profit of applied research.

It will be many decades before this perversion of our institutions of higher learning reveals its effects but then it will be too late to rectify the error. It will then be just another setting of the sun of Tyre, Acre and Sidon.

—G.F.N.

Quality THAT NEVER VARIES

with New ARCO HOT SPRAY

Another example of Arco's RESEARCHED PROTECTION at Douglas Aircraft Co. El Segundo, California

NO VARIABLES ALLOWED in finishing aircraft for the Navy! That's why Douglas Aircraft employs the Arco Hot Spray System, which gives constant viscosity regardless of hour-to-hour fluctuations in humidity and room temperatures. The Arco Control-Temp* unit gives maximum flow-out at all times... minimizes such causes for rejects as orange peel and excess blushing. And Douglas reaps an extra dividend in savings up to 50% in finishing time.

*Patent applied for.

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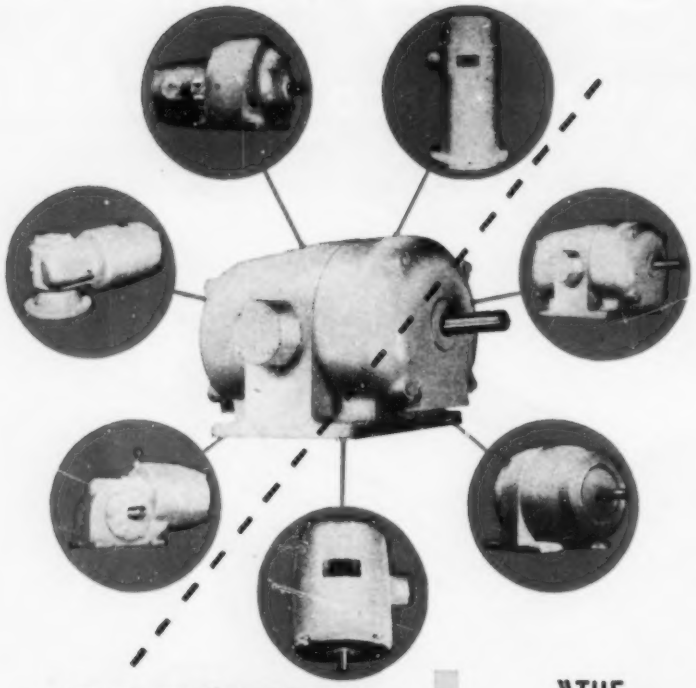

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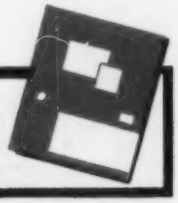

Electra ELECTRA MOTORS, INC.
ANAHEIM, CALIFORNIA

ENGINEERING ABSTRACTS

Induction Brazing and Soldering

Abstracted from "Production Brazing and Soldering by High Frequency Methods," *Mechanical World*, July 1952, London, England, by Frank Spicer, Metal Finishing Consultant.

WHEN A MATERIAL capable of conducting an electric current is placed within an alternating magnetic field eddy currents are induced in it, the dissipation of which in the conducting material produces heat which raises the temperature of the material. Currents may be induced by available equipment at frequencies varying from 200 to several million cycles per second.

The effectiveness of the transformation depends upon the space between the coil used to produce the magnetic field, and the workpiece, and the electrical resistance of the work being heated.

Alternating currents tend to flow along the surface of a conductor, and the higher the frequency the more concentrated they are at the surface. Thus the resistance of the load becomes greater as the freqency is increased.

High frequency heating can be derived from the following sources:

(a) Motor generator sets operating at a single frequency chosen from the range 200 to 15,000 cycles per second.

(b) Spark gap oscillators operating in the region of 300,000 cycles per second.

(c) Valve generators which can operate up to 10,000,000 cycles per sec and in some instances even higher.

The induction heat is focused upon the joint to be brazed or soldered by a work coil of tubular copper which is water cooled (it is known as the inductor). It heats the thin zone of metal so quickly that a brazing alloy flows smoothly into the joints before the remainder of the part can become overheated. This results in a good joint, few rejects, and a low heating cost.

The copper coil or inductor is connected to the output side of the generator, and the component to be heated is placed within the coil, but not in contact with it, so that heating occurs only in the area immediately adjacent to the coil. Therefore it is possible to obtain local heating by the choice of a suitable coil.

Correct design of the inductor coil

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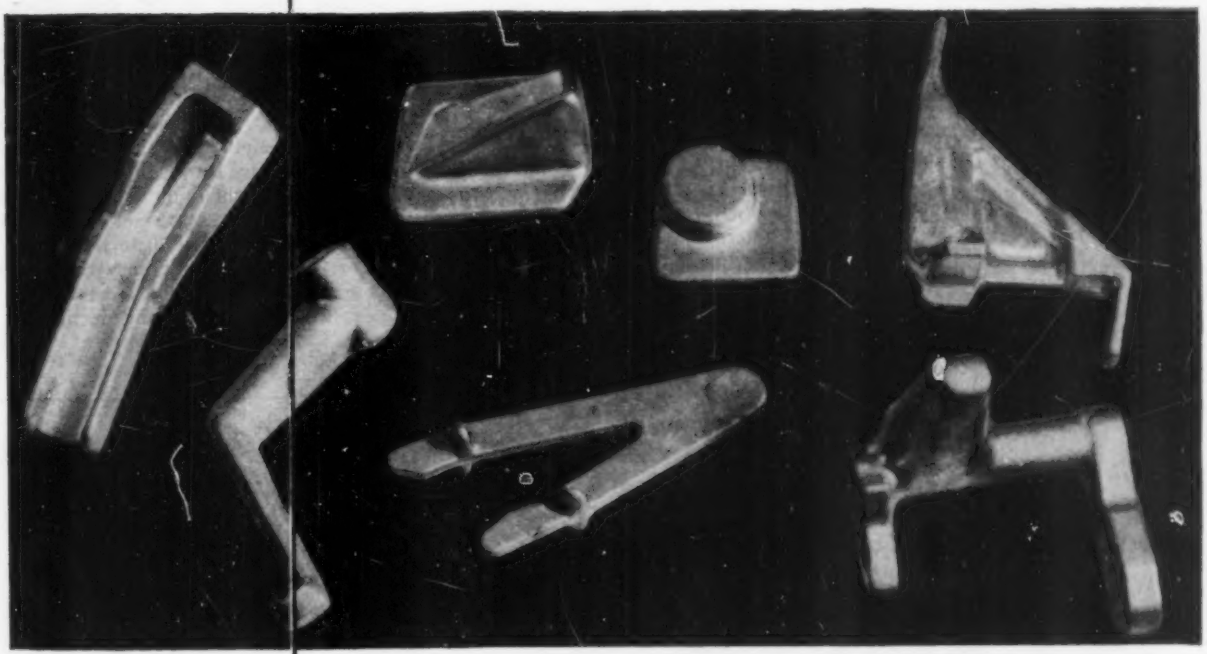

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2. **Independent mounting.**
3. **Clutch type converter.**
4. **Direct drive-BRAKING FEATURE converter.**

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Center: Clutch-type Converter.
Below: Converter with Chain Housing.
Top: Direct Drive Braking Feature Converter.

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is important and due to the various shapes that have to be brazed or soldered no set rule can be laid down. The true guide is experience.

It is not always easy to design coils to follow the exact contours of the job being heated, but alteration of the frequency will often produce the suitable results desired.

The coil shapes that can be used are infinite and some ingenious designs have been produced.

In making the coil the aim is to obtain as many turns as possible within a given area of work. The coil may be flattened or of round or square section, and after forming there must be no contact between the layers of the coil. In small coils the stiffness of the tube will be enough to maintain an adequate air gap between turns; if not, insulators of Paxolin, mica or similar substances may be used. Before shaping, the tubing should be annealed to soften it, then roughly formed, annealed again, and then finished upon a former. It is also advisable to make the connecting leads as short as possible.

Fixtures for holding parts and inductors are specially designed to a wide variety of work.

Care should be taken in designing a joint to be silver soldered or brazed. The strength of the joint depends upon the area of the film of brazing material in sound contact with the joined parts. After soldering, these joints can be used at temperatures up to 400 C before any weakening of bond strength takes place. Some typical joints are shown in Fig. 1.

Alloys containing silver used for brazing possess several outstanding features. Some of these are:

1. Low melting point, which offers quicker joining without overheating.
2. High strength and ductility.
3. Rapid penetration of closely fitted joints.

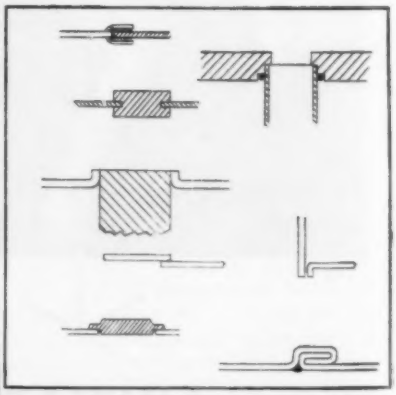

FIG. 1—Good joints, require care in their design. The methods depicted here have all been used successfully.

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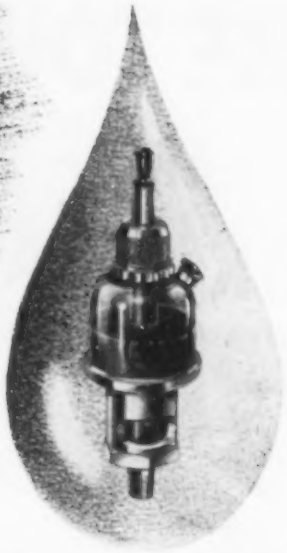

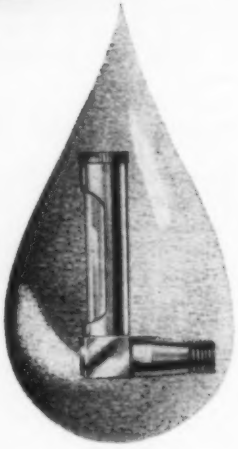

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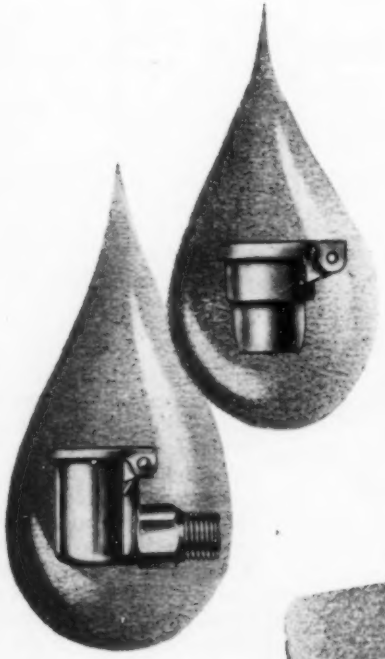
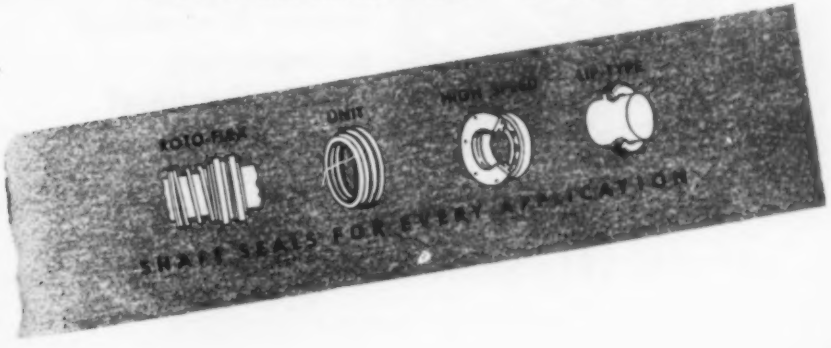
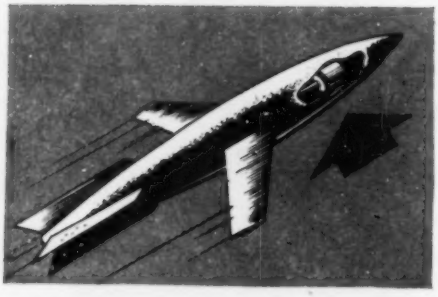




THE TOUGH ONES ARE OUR MEAT



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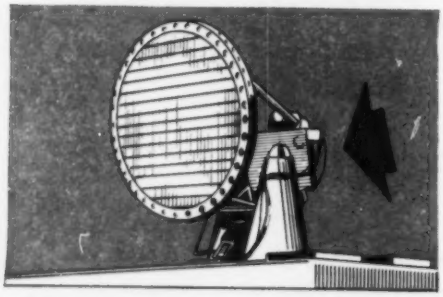
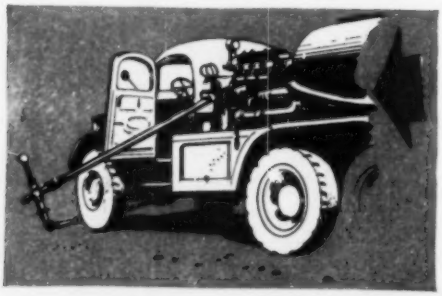
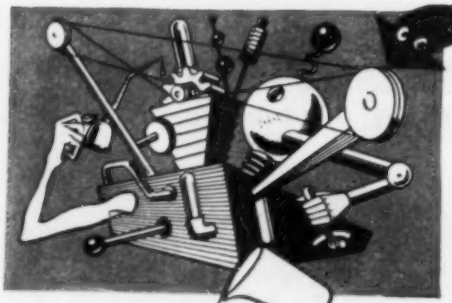


A sturdy protective casting for a radar screen box . . .



A ¼ ton pump housing . . .



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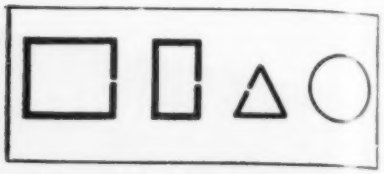


FIG. 2—Brazing metal in the form of wire, sheet, etc., is readily formed or cut into shapes which fit readily into the assembly of parts to be joined.

4. Ease in making strong joints between dissimilar metals.

The content of the silver may vary from 5 to 80 percent and choice depends upon the job to be done. The following factors must be taken into consideration:

(a) Flow temperature
(b) Properties of metals to be joined.
(c) Color match
(d) Corrosion resistance
(e) Ductility required, etc.

Silver alloys are used to braze stainless steels, copper alloys and such dissimilar metals as nickel-silver, and stainless steel.

The satisfactory use of the alloys depends on how they wet the surface of the joint and form a bond of satisfactory strength, and yet be of minimum thickness and devoid of gas holes and flux inclusions. It is interesting to note that a thickness of 0.002 in. possesses a tensile strength in the region of 140,000 psi while one of 0.020 in. possesses only 60,000 psi, therefore it is advisable to keep the fit of components to be joined as close as possible.

The alloys are made in various forms such as wire, shapes, rods, sheets, powder, strip, etc. The usual method is to purchase the required gage of metal, Fig. 2, and form it to the desired shape for the job. This is easily accomplished

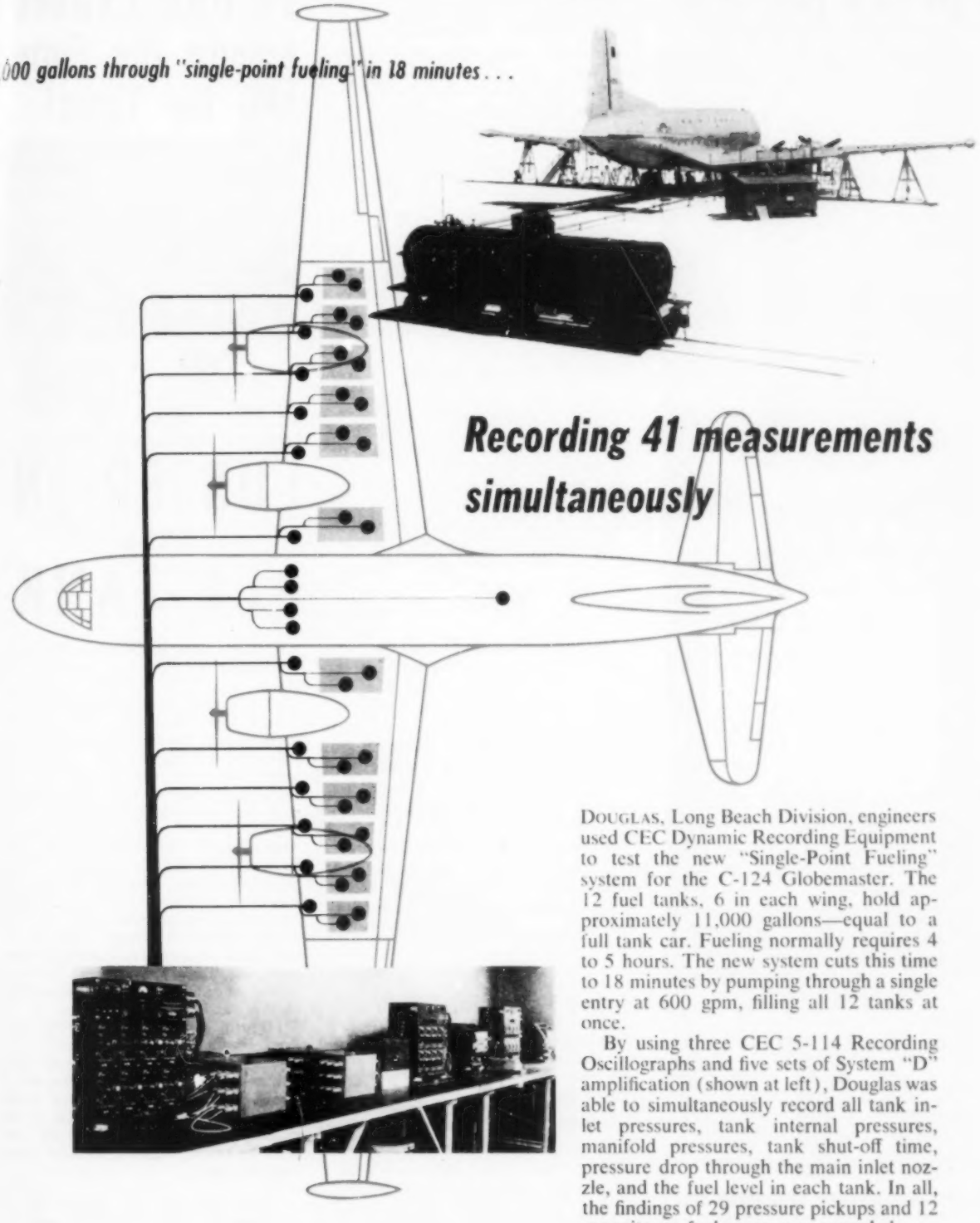
The requisites to a good soldered joint, other conditions such as correct material temperature, joint design, etc., being to standard, is a good flux. A flux possessing the following should be avoided:

(a) High surface tension which resists flow over surface.
(b) Poor penetration of joints
(c) Non-cleaning properties

A flux should be capable of wetting the surface to be brazed and should be chemically inert to the mating metals, to prevent oxidation of the joint and to render fusible the oxides of higher melting point than the metals themselves.

Cleanliness is the watchword in all metal joining operations and pre-cleaning treatment must be carefully chosen

11,000 gallons through "single-point fueling" in 18 minutes . . .



Recording 41 measurements simultaneously

DOUGLAS, Long Beach Division, engineers used CEC Dynamic Recording Equipment to test the new "Single-Point Fueling" system for the C-124 Globemaster. The 12 fuel tanks, 6 in each wing, hold approximately 11,000 gallons—equal to a full tank car. Fueling normally requires 4 to 5 hours. The new system cuts this time to 18 minutes by pumping through a single entry at 600 gpm, filling all 12 tanks at once.

By using three CEC 5-114 Recording Oscillographs and five sets of System "D" amplification (shown at left), Douglas was able to simultaneously record all tank inlet pressures, tank internal pressures, manifold pressures, tank shut-off time, pressure drop through the main inlet nozzle, and the fuel level in each tank. In all, the findings of 29 pressure pickups and 12 capacitance fuel gages were recorded.

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Dynamic Recording Systems

such as the one shown here are designed and manufactured by Consolidated. Variations in the arrangement of the equipment are infinite. Applications are widely varied throughout industry and the sciences. A typical recording system includes pickups, amplifiers or bridge balances, and a recording oscillograph. Write for Bulletin CEC 1500B.

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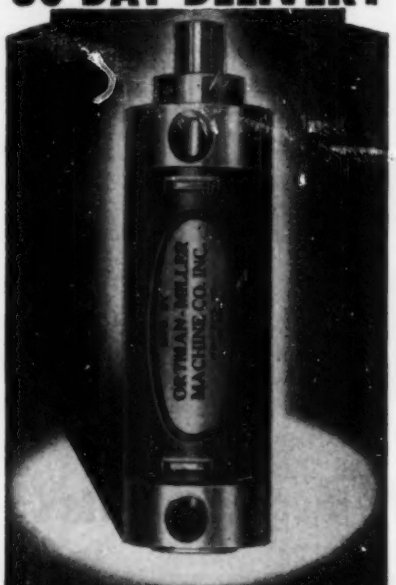

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and controlled. Where only a light film of oil exists, degreasing in hydrocarbon solvents usually suffices, but where scale or oxide exists, mechanical cleaning by abrasives or shot-blasting or by pickling in acid, must be carried out.

Silver brazing or soldering must therefore follow these requisites:

1. Correct design of joints and cleanliness.
2. Clean surface.
3. Suitable filling or brazing alloy.
4. Correct fixtures for assembly.
5. Correct fluxing.
6. Correct heating and flowing of the filling alloy.
7. Cleaning after joining.

Conclusion

The main savings of induction heating are apparent. We have a good product in a short time and with unskilled labor, therefore efficiency is high and loss of heat is only due to radiation from the components and then only for a short time. Power is only used when and where it is necessary once the generator is in operation or the valves warm.

Unskilled labor can be used once the method of soldering has been determined. This is brought about by the use of special timing devices and automatic feeds. The absence of dirt and the elimination of fire hazard improves working conditions. The apparatus can be introduced into any part of a production line, thus enabling parts to be heated "on the spot."

Uniformity of the product is assured once conditions have been ascertained, and the speed of heating is particularly helpful where large-scale production is desired.

Electro-Machining Method

Abstracted from "Another Electro-Machining Method Shows Promise," *The Iron Age*, May 29, 1952, Chilton Publishing Co., 10 E. & 42nd St., N. Y. 17, N. Y., by I. Weber, Chemist, Pitman-Dunn Laboratories Dept. Frankford, Arsenal.

ELECTRO-EROSIVE METHODS for machining carbides and hard metals can be used for cutting, grinding, boring, shaping, and tapping. Research on elector-erosive cutting and grinding is being done at Army Ordnance's Frankford Arsenal. Primary importance of the method is the fact that unlike mechanical processes, cutting and grinding rates are not affected by the hardness of the material being machined. So industrial diamonds are not needed.

Unlike electro-mechanical machining methods, the electrolytic and elec-

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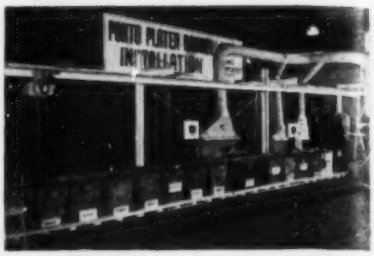

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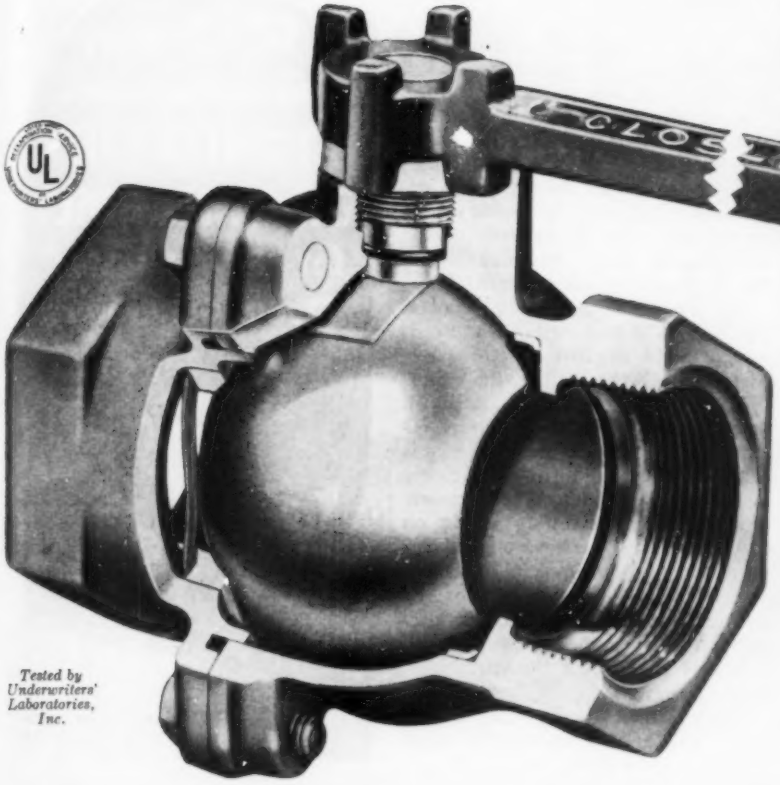
Send for free data sheets on Luster-On and Pla-Tank and set of license plate bolts shown.

THE Chemical CORPORATION
59 Waltham Ave., Springfield 9, Mass.



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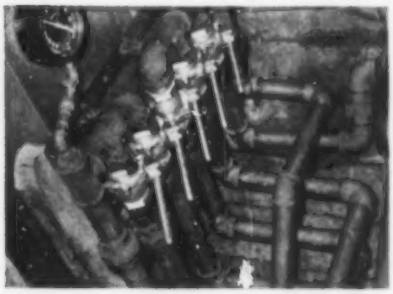
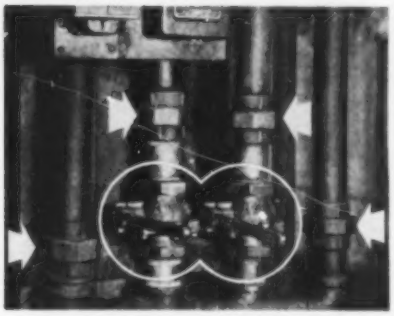
Underground, tests 4" cast iron water pipe. Operates 600 times a day. Says Warren Pipe Company's plant engineer . . . "Rockwood Cast Steel Valve is definitely superior to any other . . ."



On High Seas, in discharge manifolds, Rockwood Ball Valves perform perfectly under hazards of salt water, fish scales, wood splinters and dirt. "Outwear and outperform all valves previously used," says Hub Machine Company.



At Annealing Furnace of Revere Copper and Brass, Inc., Rockwood Ball Valves are used for quenching 60 times a day under 100 p.s.i. "They last four times longer than others," says user.

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tro-arcing processes have a cutting tool and workpiece surrounded by an electrolyte rather than a dielectric fluid. The carbide is connected in a d-c circuit as the anode, and a rotating metal disk acts as a cathode. Both cutting and grinding may be achieved, depending on whether the carbide is held against the edge or the side of the disk. In this article the results of research on cutting are reported.

The Frankford Arsenal test apparatus has a mild steel cutting wheel connected to the negative post of a rectifier, through the shaft of the motor, by means of a commutator and brush arrangement. A work clamp is attached to a lever arrangement which is completely insulated from the motor by a block of plastic. Work pressure is controlled by a sliding weight on the lever arm. Rectifier output is a maximum of 120 amp at 30 v, d-c. The work and lower portion of the cutting wheel are submerged in electrolyte contained in a plastic trough. A plastic shield over the wheel prevents splashing.

In a new model being built the electrolyte will be sprayed over the work by means of a pump and nozzle arrangement. The work will be clamped in a universal vise, and pressure and direction of feed will be controlled by a movable table.

Because of a scarcity of carbide blanks of suitable dimensions, mild steel, 23 Rc, was used for most of these tests. Results were frequently checked with carbide-tipped tools.

One of the first tests performed showed that pressure on the work has no effect on cutting time. Practical considerations of vibration required a certain minimum pressure, and too much pressure jammed the apparatus. But within this wide range, high pressure was not required to get good cutting time.

Sodium Silicate Best Electrolyte

A number of electrolytes and quenching fluids were tested to find the fluid which gave lowest cutting time. Sodium phosphate, sodium borate, sodium aluminate, sodium molybdate, sodium citrate, sodium oleate, and sodium hydroxide were tested. Two non-electrolytes, water and lubricating oil, were included for comparison.

Test results in Fig. 2 show that cutting time decreases as current increases. The curve approaches a level eventually, so that for practical purposes and economy there is an optimum current beyond which there is little point in increasing current.

In Frankford test results, shown in

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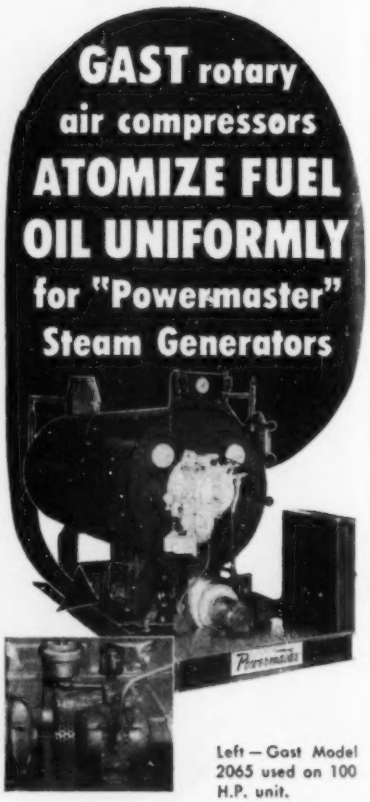
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Left — Gast Model 2065 used on 100 H.P. unit.
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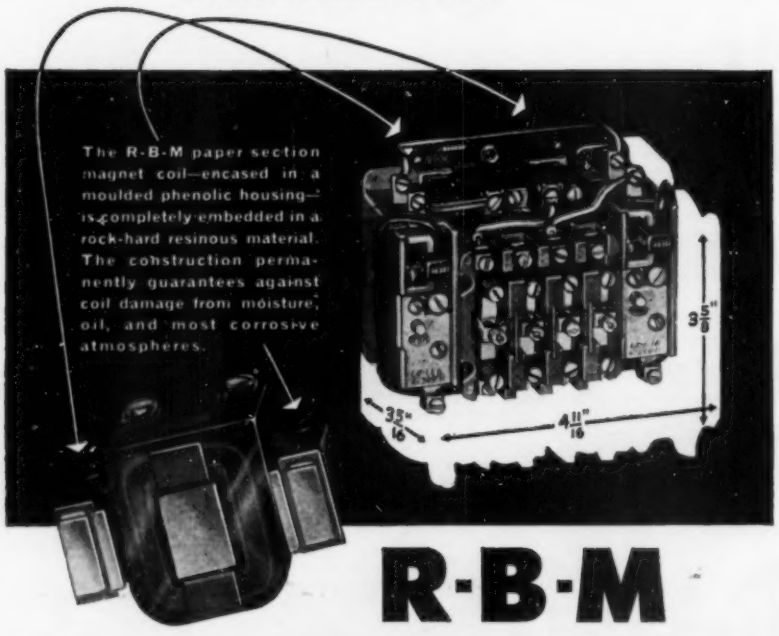
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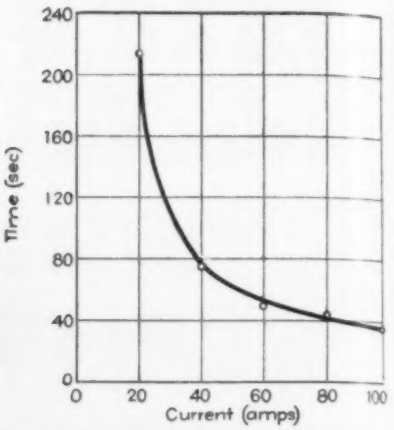

FIG. 1—Plot shows how cutting time decreases with increasing current flow. Curve tends to level out to point where current increases yield little time gain.

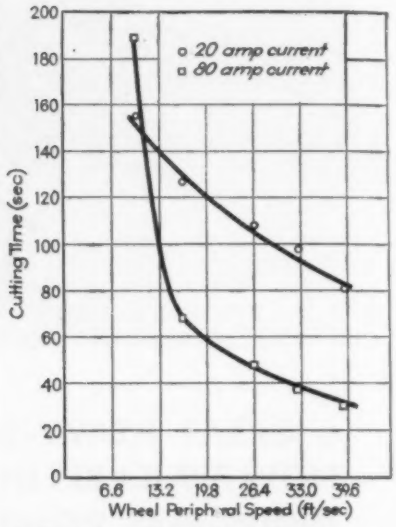

FIG. 2—At two different amperages, cutting time decreases as wheel peripheral speed increases, though the amperage obviously affects the process.

Fig. 3, cutting time decreased as wheel peripheral speed increased, at any value of current. Russian investigators have claimed that cutting time increases as peripheral speed increases. The Russians were working in a speed range of from 30 to 195 fps, while Frankford speeds ranged from 10 to 39 fps. Frankford intends to investigate at higher speeds.

In early tests, wheels were machined on a lathe to a definite thickness and diameter, and were generally shaped to a flat-edge rim. It was found that as a wheel was used, the first 12 to 15 cuts took a fairly long time. Continued use of a wheel usually resulted in a sudden decrease in cuttime time to a stabilized reproducible value. Visual examination showed that a bevel was

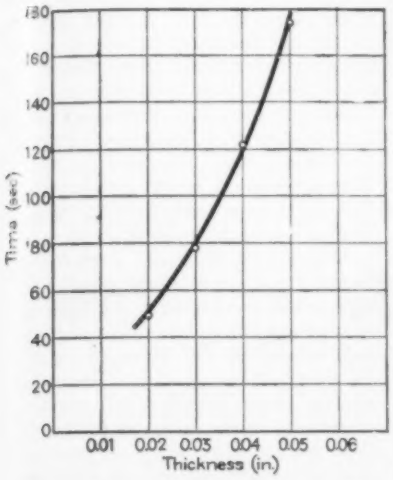

FIG. 3—Thinner wheels cut faster. The cost of making wheels as thin as 0.02 in. is high. But reduced cutting time justifies this. Wheels could be thinner.

produced on the wheel rim in use. Therefore a wheel was prepared with a machined bevel. With this, cutting time for the first few cuts was lower than before, and stabilization occurred after about 5 cuts.

Hardness Doesn't Affect Cutting Time

Table I gives the results of tests of the influence of hardness on cutting time. The cutting times, averaging 69 sec, showed normal dispersion, leading to the conclusion that hardness has no effect on cutting time. These tests were made on carbon tool steel. Similar tests were made on cobalt steel of 65 Rc hardness, with an average cutting time of 31 seconds. The difference between the two averages is believed by Russian investigators to follow the rule that resistance to cutting decreases as the atomic weight of the element increases. Insufficient tests have been conducted at Frankford to support or refute this.

When wheels with thicknesses of 0.02, 0.03, 0.04, and 0.05 in. were tested, it was plain that cutting time was much lower with thinner wheels.

Hardness Influence on Cutting Time

Specimen	Hardness, Rc	Cutting Time, Sec
1	64.2	70
2	61.0	75
3	54.2	61
4	44.2	69
5	37.0	66
6	24.5	71
		s = ± 4.8 sec

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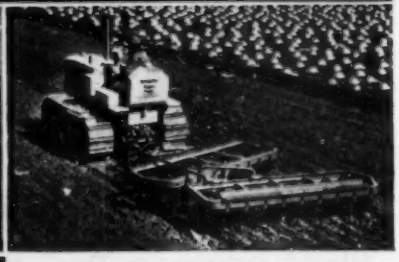

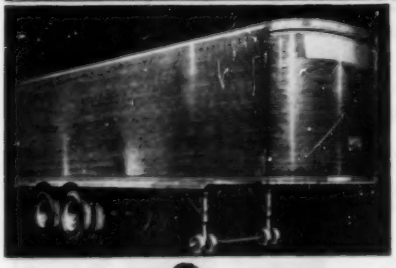

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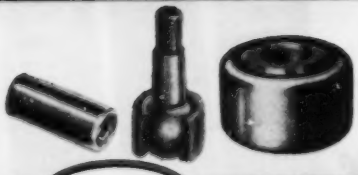

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as Fig. 4 shows. Loss in wheel diameter, for the same number of cuts, was less with the thinnest wheel than with the others. The thin wheels are difficult to prepare, but are practical from the standpoint of decreased cutting time, low rate of diameter loss, and more economical power consumption. Wheels thinner than 0.02 in. would be desirable, but impractical.

The process described is primarily intended for high speed shaping of hard metals and carbides, and does not produce a good surface finish. In general, the higher the speed of cutting the rougher the surface. The usual machine shop procedure of grinding or lapping machined parts to the desired surface finish may be practiced after electroarc cutting. In addition, tentative and exploratory experiments in electrolytic grinding indicate that it is possible to obtain surface finishes that are smoother than finishes obtained by usual mechanical methods.

An Arc Cutting Process

It has been concluded at Frankford that the process is predominantly an arc cutting process. If a gap is maintained between the rotating wheel and the workpiece, the only phenomenon occurring is electrochemical, with a deposition of a silicate film over the anodic workpiece. There is no possibility for self-initiated sparkover, since the voltages seldom exceed 20 volts. In actual practice, a gap between the electrodes is constantly being opened and closed as a result of natural vibration. At the moment the two electrodes separate, an arc is initiated. It is maintained until quenched either by too large a gap distance or by the sodium silicate solution. The arc is of relatively long duration as compared to a spark, and because the arc has a higher integral temperature, erosion of the anode is predominantly a thermal effect.

The deposited dielectric silicate film is very effective in directing the forces of arc erosion toward the bottom of the cut. The coating stays on the sides, but is removed from the bottom of the cut by wheel contact. Other electrolytes may be used, but silicate is most effective.

Welding 17 Cr Stainless

Abstracted from "17 Cr Stainless Replaces 18-8 in many Weldments," *The Iron Age*, June 26, 1952, Chilton Publishing Co., by G. E. Linnert.

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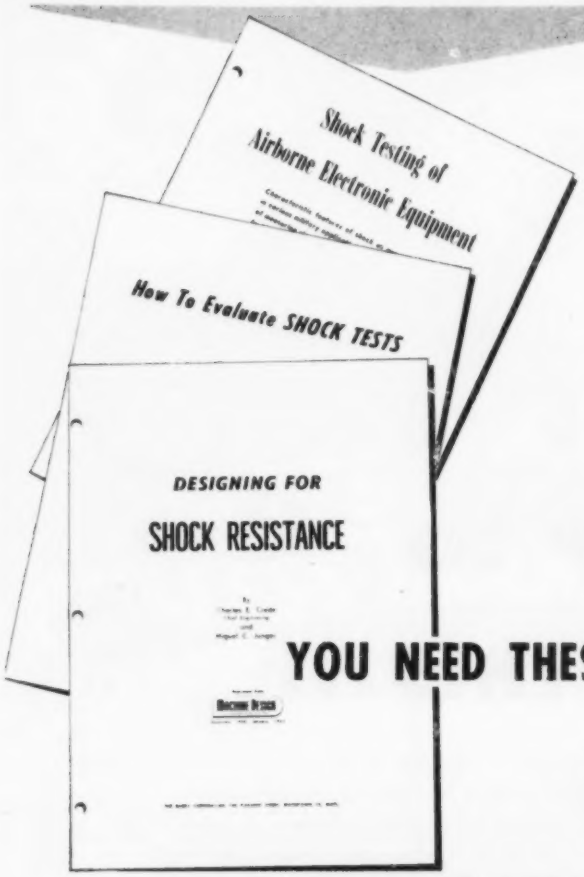

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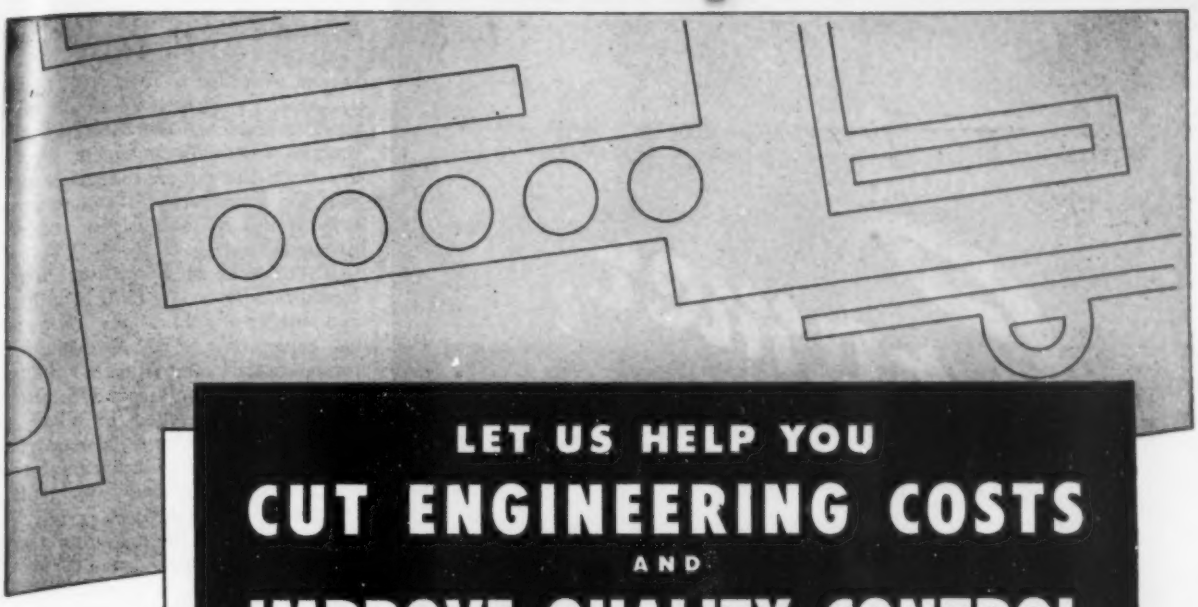
nickel containing metals now in short supply have singled out 17 pct chromium stainless steel (AISI type 430) as the most promising. However, the properties of type 430 stainless steel differ sufficiently from those of more familiar grades of austenitic 18-8 stainless steel, to warrant a close study before attempting to use the material in a given application. The welding characteristics and properties of 17 pct Cr steels require perhaps the greatest amount of consideration because welding is often the principal method of assembly.

When seeking an alternate for 18-8 stainless steel in a particular application, the lower chromium steels like type 410 with 12 pct Cr probably will not offer sufficient corrosion resistance. Should 12 Cr material be found entirely satisfactory, then the previous use of 18-8 was a case of over-grading. Type 410 is classed as a martensitic grade, which signifies that the material is hardenable. Its hardenability is high enough to present a problem in welding where the base metal heat-affected zones become hardened and consequently suffer loss of ductility. While this problem can be minimized by restricting the carbon content to a low level or by use of the aluminum containing type 405, the corrosion resistance of 12 Cr steels is usually the factor which limits their application.

The higher chromium stainless steels like 442 (21 pct Cr) and type 446 (27 pct Cr) are classed as ferritic steels and have somewhat better corrosion resistance than the type 430 steel containing 17 pct Cr. However, no simple relationship exists between chromium content and corrosion resistance, and it cannot be assumed that the resistance of these materials will be commensurate with their chromium content.

The majority of type 430 steel is manufactured with a chromium content in the range of 16 to 18 pct and a low carbon content to produce a steel which is essentially ferritic. If this material is heated within or above the critical range (lower temperature approximately 1,600 F) and cooled, for example, as occurs in the narrow heat-affected zones adjacent to a weld, the small amount of hard martensite will form in the matrix of soft ferrite. Ferrite grain size also increases when 430 is heated above approximately 1,750 F. These two structural features, ferrite grain growth and martensite formation, are the factors which exert the greatest influence on the properties of a weld joint because both reduce the toughness and ductility of the metal.

A relatively small amount of ti-



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tanium is needed to make 17 Cr steel a completely ferritic steel. As indicated in Table I, 430 Ti customarily contains a titanium content of at least five times the carbon content to prevent the formation of austenite upon heating and consequently of martensite upon cooling.

The absence of a structural transformation allows 430 Ti to be utilized in a number of applications. The sudden expansion which accompanies the formation of martensite no longer takes place on cooling and therefore the steel can be used in television cones where glass-to-metal seals are made. Table II lists mechanical and physical properties for the two grades, and 18-8 prior to welding.

Unfortunately, the transition range for the 17 Cr steels lies just above room temperature. The material will be notch sensitive under impact loading at room temperature and below, and will display Izod values of possibly 20 ft-lb or less. When tested at temperature in the neighborhood of 200 to 250 F, the Izod values will increase to approximately 30 to 50 ft-lb. Sharper notches and lower temperatures reduce impact resistance.

The characteristic to be kept foremost in mind when planning the design of a welded 17 Cr article is the notch sensitivity of these steels as measured by notched-bar impact testing. The conditions under which this sensitivity will cause difficulty are not easy to predict. Almost any piece of equipment designed to withstand static loading may at some time be subjected to accidental or unforeseen impact loading. Loss of notched-bar impact toughness can be taken as fair warning that the material will not be able to accommodate any appreciable multiaxial stresses even under slow rates of loading. Since

Typical Properties of Chromium and Chromium-Nickel Stainless Steels in The Annealed Condition

Property	18-8 Types 302 and 304	17 pct Cr Type 430	17 pct Cr + Ti Type 430 Ti
Tensile Properties:			
Ultimate Tensile Strength, PSI	90,000	75,000	65,000
0.2 pct Yield Strength, PSI	40,000	45,000	45,000
Elongation in 2 in., pct	55	25	30
Hardness, Rockwell B	80	85	80
Izod Impact Strength, V-Notch, Ft.-Lb.	100–120	15–50	
Endurance Limit, PSI	34,000	40,000	
Coefficient of Thermal Expansion, Per Degree F (Mean value 32 to 1000°F)	10.2×10^{-6}	6.3×10^{-6}	6.3×10^{-6}
Thermal Conductivity: BTU/hr/sq. ft/ft/°F at 212°F	9.4	15.2	

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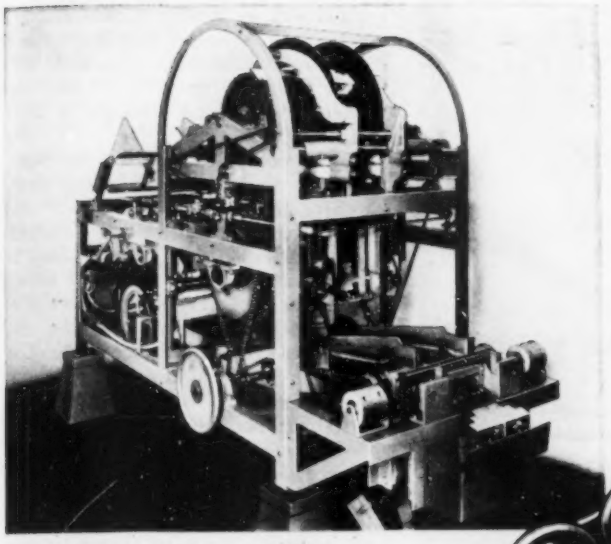

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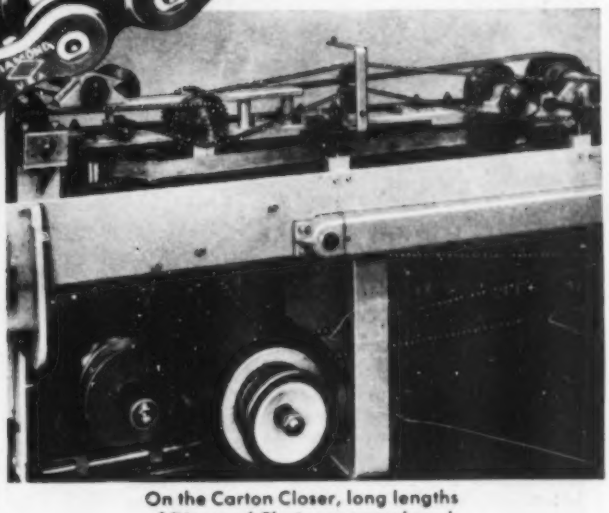

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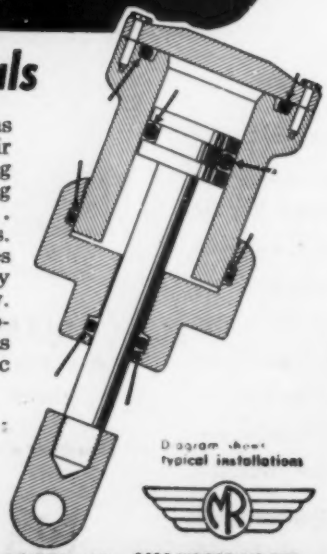

Diagram shows typical installations

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stresses of this character are common in welding, particularly in heavy sections, avoid notches and points of stress concentration when possible.

In designing a welded article the sizes of available material should be considered and an attempt made to relegate weld joints to the least-stressed portions of the weldment. Joint designs which include inherent notches should be avoided. Corner joints and Tee joints, particularly those made with incomplete penetration, are examples. A simple butt joint made with full penetration represents the most desirable type of joint and can often be arranged through a little planning.

It is good practice to have the bending take place across the rolling direction of the sheet. Bending 430 and 430 Ti parallel to the rolling direction, particularly if the corner radius is sharp, may result in cracking along the corner. By bending corners and locating the joint in a flat section, the butt-joint is readily accessible for grinding flush, and, if necessary, X-ray inspection.

In dynamically loaded structures, the design engineer must be on guard, to avoid failure through fatigue. The 17 Cr steels are not especially prone to fatigue failure. However, this form of fracture is the most frequently encountered type of mechanical failure in weldments of all grades of steel. A notch or a sharp change in section is usually found to be the underlying cause of premature fatigue fractures. A stress of four or five times the expected value can easily be concentrated at the toe of a fillet weld and in this way exceed the endurance limit of the material. Sometimes a machining operation subsequent to welding can be used as good insurance against stress concentration.

Distortion in 430 and 430 Ti is easier to control than 18-8 material. The lower coefficient of thermal expansion of the 17 Cr steels will result in less warpage subjected to the welding heat. In addition, the higher thermal conductivity will help diffuse the heat from the weld zones. When welded articles must be true to shape and dimensions even the 17 Cr grades should be carefully clamped. These should be sufficiently rigid to overcome the tendency to warp during welding, and should have enough mass to help dissipate the heat.

There are advantages to preheating for welding which apply to many steels. It may appear quite logical that for 430 and 430 Ti base metal each should be joined by a weld metal of essentially the selfsame composition. This is seldom the case. A fact not

widely appreciated is that wrought metal compositions do not often provide good weld metal; and this is particularly true of stainless steels. Bona fide welding rod is made to specially modified analysis requirements to insure good weld metal properties. The use of no filler rod, or thin shearings from the edge of the parent sheet as filler metal, is not the best practice.

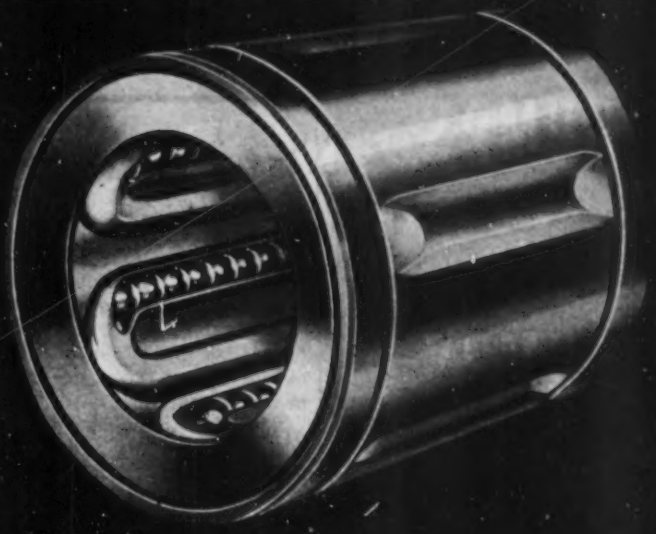
Type 430 weld metal as formed during any fusion welding process is low in toughness and ductility, even more so than the heat affected zone of 430 base metal. The as-deposited structure of coarse columnar ferrite grains and martensite accounts for the very low ductility. An article joined with 430 weld metal should be heat-treated after welding to improve the toughness of the weld metal. The benefit secured by annealing 430 weld metal can be seen by the comparison of mechanical properties in Table III.

An austenitic Cr-Ni filler metal is frequently used to join 17 Cr steels to secure a ductile weld metal in the as-welded condition. For 430 and 430 Ti a 308 (20 Cr-10 Ni) covered electrode or a 308 bare rod is generally selected, although almost any austenitic welding material, such as types 309, 310, or 347, can be applied. These Cr-Ni materials will provide a very tough, ductile weld-metal in place of the comparatively brittle 430 weld metal. The use of Cr-Ni weld metal does not prevent grain growth in the base metal heat-affected zones of either grade, nor martensite formation in 430. The bending ability of the weld joint is improved as a result of having highly ductile weld metal present. Despite this advantage of employing Cr-Ni weld metal to join the 17 Cr steels, the austenitic type of weld metal must not be indiscriminately applied. Applications may arise where the difference in color, physical characteristics or mechanical properties of the austenitic weld and ferritic parent metal will cause difficulty. The greater coefficient of thermal expansion of the weld metal is also cause for concern.

Type 308 v 430
Typical Properties of Weld Metal Deposited by Metal Arc

Condition	20-10 Type 308 Weld Metal As-Welded	17 Pct Cr Type 430 Weld Metal	
		As-Welded	Annealed 1450°F
Tensile Properties:			
Ultimate Tensile Strength, PSI.....	90,000	95,000	75,000
0.2 pct Yield Strength, PSI.....	55,000	ND	50,000
Elongation in 2 in..	40	3	28
Charpy Impact:			
Keyhole Notch, Ft-lb.....	30	1	20

BALL BUSHING



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WRITE FOR CATALOG

OUR READERS SAY

Air-Conditioned Automobiles

To the Editor:

Recently in our local newspaper we noticed a news item from PRODUCT ENGINEERING regarding air-conditioned automobiles in the near future. We would like to advise that the Lone Star Motor Co. here in El Paso is way out in front as far as air-conditioning in cars is concerned.

We have installed approximately 200 refrigerated air-conditioning units in Cadillacs and Oldsmobiles over the past three years. These units are highly successful, and people using them have much praise for their efficiency and comfort.

I do know that General Motors is experimenting with Frigidaire air-conditioning in cars at the present time, and am sure that we will have them as standard equipment in 1953.

Thought you might be interested in knowing how far Texas is ahead of the rest of the country.

W. H. WOOLDRIDGE, PRES.
Lone Star Motor Co.

Ed—Ya-a-y Texas

More 12 Place Math

To the Editor:

It was highly gratifying to me that you saw fit to print Mr. John E. Whiteside's remarks concerning duodecimals, to which you added a brief exposition of the workings of this system.

Your readers may, however, get the impression that the system of measuring by duodecimal notation is somewhat jumbled, inasmuch as you set forth the "Mechanics Scale" and the "Basic Scale", wherein the units of one are intermediate in value to units of the other. This is one illustration of a dilemma that has hindered what I consider the very desirable adoption of the suggested system, namely whether to design units of the new system around familiar units, as far as possible (such as inches, feet), or start out fresh with entirely new units chosen for particular functional advantages or for association with scientifically-determined values. Each system has its merits, and if the proponents of duodecimals could consolidate behind one

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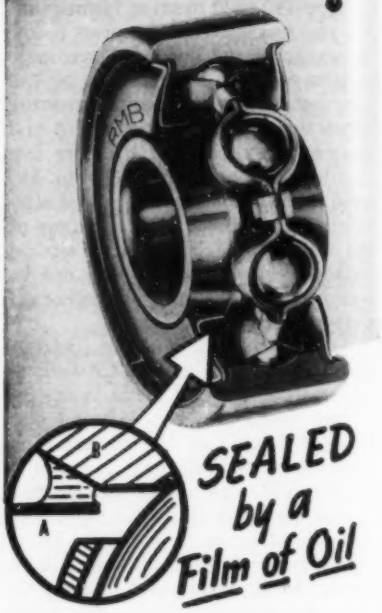

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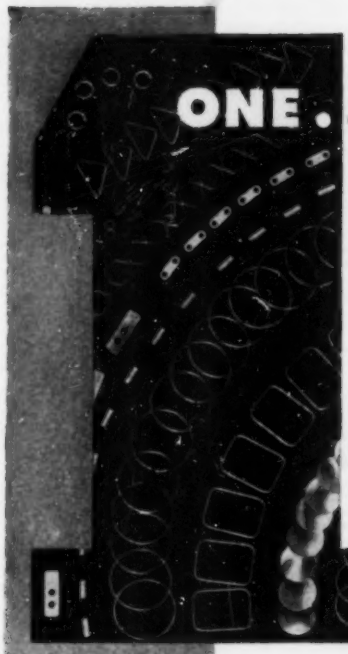

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of them I believe great progress could be made.

Doubtless you will get the usual objections from people who think there is something "wrong" with duodecimal "decimals", that "you can't have logarithms", that "trig formulas won't work out", and various other complaints based on a belief that there is something inspired or "natural" about the usual decimal system. None of these objections will stand analysis, but in fact there are some attributes of duodecimals that actually fit geometric and spatial relationships better than our present measures. Consider the twelfth part of a circle. This is 30 deg of our present measure (wherein 90 deg is a quadrant and 360 deg a circle, both completely arbitrary numbers chosen to facilitate computations), but would either have a name of its own in duodecimals, in which case it would be a unit quantity, or would be referred to as "0.1 circle" (i.e., 1/12 circle). There is no point in doing this in our present numerical system, because 1/10 of a circle is a particular angle which happens to be 36 deg in our present system of measurement, a quantity which is occasionally of use to designers of gears, cams, stars, and Pentagon buildings, but not much otherwise.

Mr. Whiteside prefaced his remarks by referring to computing devices, and might have taken the opportunity to emphasize the virtues of duodecimals in connection therewith. Present-day machines mostly operate in binary systems and variants thereof, because the electronic stages mostly are "either-or" arrangements, wherein the unit cycle repeats after the second step. True, some counters operate decimally by counting around a ring of ten stages, or by using four binary stages (16) and dropping out the extra 6 along the way, or by using a system such as biquinary notation, involving a binary stage and a five-place ring in tandem to make ten. The last-named is the only one that reads decimally and is reasonably economical of stages (7). The same seven stages, arranged 4 and 3 for what I call ter-quaternary notation, can count to 12. The two extra counts do not look like very much, but in large-scale, high-precision operations it will be found that 13 duodecimal orders are more than the equivalent of 14 decimal orders so that a whole order (7 stages) is saved in devices of this capacity. Even if no stages are saved, as in smaller machines, the precision is enhanced because a given number of digits represents a larger quantity duodecimally, or conversely, a change of one unit in

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The plants of Arwood are planned and built to be efficient, to manufacture economically and to deliver the utmost in quality and finish. The personnel is carefully selected and trained to produce to Arwood's exacting standards of manufacture.

These facts about Arwood production are of importance. The design and die division, for instance, has made literally thousands of intricate moulds and has the experience to answer the most difficult design problems. The cam illustrated is a typical example. Arwood, too, is able to cast in both ferrous and non-ferrous metals to tolerances of ± .002 to ± .005. Whether a quantity is large or small flexibility in design makes it economical. Service is another factor. Resident sales engineers throughout the country are able to give you valuable information quickly.

Here are a few practical results of the Arwood operation. A part was designed and made three times stronger than it had been made before at a 90% saving. Another application combined seven parts into one. And many times, after careful study, precision casting parts were made that could be made no other way. Arwood has accepted many challenges and because of engineering skill, perfection in tooling, complete control and production efficiency, has been able to meet each one.

If you have a production problem, why don't you write Arwood. Our engineers have worked in many industries and have the "know-how" that can be helpful to you. For important information about the versatility of precision casting, write for our booklet, "Alloy Selection and Design for Investment Castings," and visit our booth, No. 1758, at the National Metal Exposition in October in Philadelphia.

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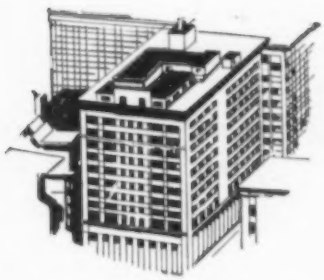

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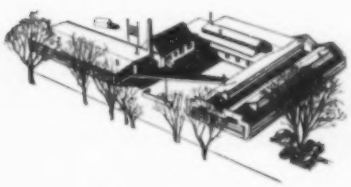

Tilton, N. H., plant

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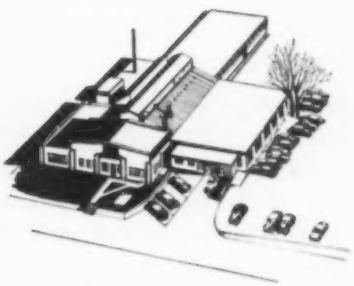

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the last place is a smaller fraction of the total quantity represented.

The last point above is related to a fact that might interest designers and machinists. Duodecimal 0.001 is really 1/1728 in our present notation, or not far from "half-a-thousandth", which we now express as 0.0005, using the fourth place of decimals. (This statement is a trifle optimistic; the value of duodecimal 0.001 is actually almost decimal 0.0006). Mr. Whitehead's remark about 1/64 being duodecimal 0.023 is interesting but is again related to the desire to save the conventional units such as 64ths; if we wanted to work to 72nds, we would proceed as follows: 0.02, 0.04, 0.06, 0.08, 0.0X, 0.10, 0.12, etc. Two-place expressions, and using only the even-numbered ones at that, for fractions finer than a 64th!

—WILLIAM C. SCHUMACHER
Brooklyn, N. Y.

Annual Handbook of Product Design

To the Editor:

Please advise how I can secure a copy of "The Annual Handbook of Product Design for 1953".

I am not a subscriber, though I do manage to secure issues of PRODUCT ENGINEERING here in the islands.

—ARTURO L. LOPEZ
Manila, Philippines

Ed—The "Annual Handbook of Produce Design for 1953" will be included in the subscription to PRODUCT ENGINEERING. A limited number of copies will be available at $2.00 per copy.

PE Article Used in College Course

To the Editor:

For some years I have been offering a course in Mathematical Computation by Physical Means. The recent article on Resistance Wire Computing Device for Solving Algebraic Equations by C. V. Ramamoorthy and W. W. Soroka in the February 1952 issue of PRODUCT ENGINEERING seems to provide suitable material for this course.

I am writing to ask your permission to reproduce this article by an offset process (Multilith) for cost-free distribution to and retention by the students (roughly thirty per year) who take this course. At the same time I am writing to the author to make sure he is willing to have his article so used. Since our method of reproduc-

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—RANDOLPH CHURCH, CHAIRMAN
Dept. Math. & Mechanics
United States Naval
Postgraduate School
Monterey, Calif.

Ed—We are glad to extend to you permission to make offset or Multilith copies of the article "Resistance Wire Computing Device," by C. V. Ramamoorthy and W. W. Soroka which appeared in our February issue.

Since you are not planning these copies for sale, and they are entirely for student use, I can see no objection whatsoever. I am pleased that you thought highly enough of the article to include it in your course.

Sources of Silicon Monoxide

To the Editor:

While reading the PRODUCT ENGINEERING magazine, I noticed that one of your subscribers was interested in finding a source of Silicon Monoxide.

We can produce this material in the form of a light brown powder that is sold at $12.50 per lb. The chemical analysis of the material is as follows:

	Percent
Material not volatile with HF	1.84
Carbon	4.40
Silicon Carbide	nil
Silicon Monoxide (SiO)	62.80
Silicon Dioxide (SiO_2)	31.00

—N. G. GRAFTON
General Electric Co.

Where Can I Get It?

Reinforced Plastics

To the Editor:

In your May 1951 issue I read on page 157 that you had previously published an article on "Reinforced Plastics" by Richard J. Francis. This article appeared in the February 1951 issue. I would like to know if a reprint of the article mentioned above is available and how I may obtain one. If a reprint is not available, I would like to know if it is possible for me to purchase a copy of the February issue.

It would also be appreciated if you can advise if other articles on the same subject have appeared in your or other technical magazines and

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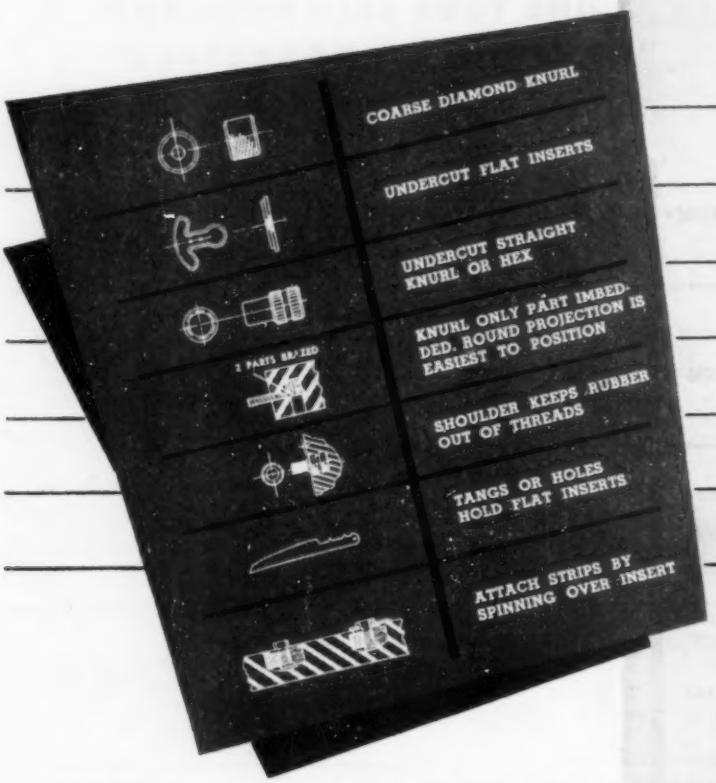
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whether there have been any books published recently on the subject.

—EDWARD HASSELL
Highland Park, N. J.

Ed—Enclosed you will find the article written by Richard J. Francis entitled "Reinforced Plastics" which appeared in the February issue of PRODUCT ENGINEERING. We are also enclosing a four-page article entitled "Glass Fiber Reinforced Plastics" which was published in our November 1951 issue.

We are unable to advise you of similar articles which have appeared in other papers but we have passed on your request to our Book Company. They will check their book list and if any books on the above subject are listed they will advise you.

Sorry, Its Private Property

To the Editor:

We often use what is known in England, and we believe also in the U. S. A., as "Easi-Flow No. 2 silver solder" and Easi-Flow flux for brazing steel and copper tubes.

We should like to receive specification and technical details of these materials such that we can make them ourselves or have them made for our own use.

—A. C. R. GREENE
Deven, England

Ed—I'm sorry to say that it is impossible for us to give you the details of Easi-Flow silver brazing solder which would enable you to make it for yourself. This product is a trademark of the Handy & Harman Company, located at 82 Fulton St., New York, New York and the formula and method of making it are their property.

Wants More Data on Heat Resistant Adhesives

To the Editor:

We are interested in the article on page 200 in your February, 1952 issue relative to some heat resistant adhesives. We would appreciate it if you could tell us where we can get some more information on this subject.

—E. W. MCGUINESS
General Electric Co.

Ed—Regarding heat-resistant adhesives, we cannot give you any brand names on these materials. The adhesives described in our February issue were developed and are being used by General Motors.

However, you can obtain any infor-

(Continued on page 283)

mation you might want from either Mr. A. J. Kearfott or Mr. C. W. Roush, at the General Motors Research Laboratories in Detroit, Michigan.

Design Games

To the Editor:

I am interested in product engineering and design as related to the game manufacturing industry. Can you suggest sources of available material covering this specialized subject?

—PAUL V. GILLETTE
Holland, Michigan

Ed—If you write to the two publications listed below, they might be able to help you. They did not deal exclusively with product engineering in the design of games, but might be able to give you some valuable leads.

Playthings, McCready Publishing Co., 71 West 23rd St., New York 10, N. Y.; *Toys and Novelties,* Toys & Novelties Publishing Co., 307 N. Michigan Ave., Chicago 1, Ill.

Paper Thermal Indicator

To the Editor:

In the May 1952 issue of your publication, reference is made to a paper thermal indicator made by the Army Quartermaster Corps.

We are very much interested in obtaining much detailed information on this indicator and would appreciate your directing us to the proper party in the Army Quartermaster Corps for such information. —A. J. LIEBMAN
Dravo Corp.

Ed—For further information on Paper Thermal Indicators you may write to Lt. Arnold S. Lott at the address below:

Publications Division
Pentagon Building
Washington, D. C.

Selenium Rectifier Users

To the Editor:

We are a user of selenium rectifiers and would appreciate further information concerning foreign suppliers of this equipment as mentioned in a defense production administration report, quoted on page 115 of your February 1952 issue. —T. W. WHITE
Ther Electric & Machine Wks.

Ed—The information on foreign suppliers of electronic equipment which we published in our February issue was obtained from a Defense Produc-

AMERICAN CHEMICAL PAINT COMPANY
AMBLER CHEMICALS ACP PROCESSES PENNA.

Technical Service Data Sheet
Subject: SPECIFICATION RUST PROOFING AND PAINT BONDING CHEMICALS

SPECIFICATION NUMBER	ACP SPECIFICATION CHEMICAL	SPECIFICATION TITLE
QQ-P-416	"LITHOFORM" "ZINODINE"	PLATING, CADMIUM (ELECTRODEPOSITED)
RR-C-82	"LITHOFORM" NO. 32	CANS, CORRUGATED: ASH AND GARBAGE, TAPER-SIDE, ZINC-COATED, WITH COVERS
MIL-C-5541 (See also QPL-5541-1)	"ALODINE"	CHEMICAL FILMS FOR ALUMINUM AND ALUMINUM ALLOYS
MIL-C-16232 Type I Type II	"THERMOIL-GRANODINE" "PERMADINE"	COATINGS — PHOSPHATE; OILED, SLUSHED, OR WAXED (FOR FERROUS METAL SURFACES) AND PHOSPHATE TREATING COMPOUNDS
MIL-E-917A (Ships)	"GRANODINE" "LITHOFORM" "ZINODINE"	EQUIPMENT, ELECTRIC POWER, BASIC REQUIREMENTS FOR (NAVAL SHIPBOARD USE)
MIL-L-3077	"PERMADINE"	LINKS, METALLIC BELT, FOR SMALL ARMS AMMUNITION
MIL-S-5002	"ALODINE" "GRANODINE"	SURFACE TREATMENTS (EXCEPT PRIMING AND PAINTING) FOR METAL AND METAL PARTS IN AIRCRAFT
MIL-V-3329	"GRANODINE"	VEHICLES, COMBAT, SELF-PROPELLED AND TOWED, GENERAL REQUIREMENTS FOR
JAN-C-490, Grade I	"GRANODINE"	CLEANING AND PREPARATION OF FERROUS METAL SURFACES FOR ORGANIC PROTECTIVE COATINGS
JAN-F-495	"GRANODINE" "LITHOFORM"	FINISHES FOR EQUIPMENT HARDWARE
JAN-L-548A	"PERMADINE"	LINK, METALLIC BELT, 20 MM., M8
JAN-T-704	"GRANODINE"	TREATMENT AND PAINTING (FOR CONSTRUCTION AND ENGINEERING EQUIPMENT)
AN-E-19	"ZINODINE"	ELECTRONIC EQUIPMENT; GENERAL SPECIFICATION FOR
AN-F-20 (See also U.S.A. 3-213)	"ALODINE" "GRANODINE" "LITHOFORM" "PERMADINE" "THERMOIL-GRANODINE" "ZINODINE"	FINISHES, FOR ELECTRONIC EQUIPMENT
U.S.A. 57-0-2C Type II, Class A Type II, Class B Type II, Class C	"THERMOIL-GRANODINE" "PERMADINE" "GRANODINE"	FINISHES, PROTECTIVE, FOR IRON AND STEEL PARTS
U.S.A. 51-70-1 Finish 22.02, Class A Finish 22.02, Class B Finish 22.02, Class C	"THERMOIL-GRANODINE" "PERMADINE" "GRANODINE"	PAINTING AND FINISHING OF FIRE CONTROL INSTRUMENTS; GENERAL SPECIFICATION FOR
U.S.A. 50-60-1	"GRANODINE"	CONTAINERS, METAL, FOR ARTILLERY AND ROCKET AMMUNITION
U.S. Navord O. S. 675	"ALODINE"	SPECIFICATIONS FOR THE MANUFACTURE AND INSPECTION OF CARTRIDGE, POWDER, AND ROCKET TANKS (ALUMINUM)
U. S. N. Appendix 6	"LITHOFORM"	INSTRUCTIONS FOR PAINTING GENERAL SPECIFICATIONS FOR BUILDING VESSELS OF THE UNITED STATES NAVY
M-364	"PERMADINE" "THERMOIL-GRANODINE"	NAVY AERONAUTICAL PROCESS SPECIFICATION FOR COMPOUND PHOSPHATE RUST-PROOFING PROCESS
16E4 (Ships)	"ALODINE" "GRANODINE" "ZINODINE"	ELECTRONIC EQUIPMENT, NAVAL SHIP AND SHORE: GENERAL SPECIFICATION
AN-C-170	(See MIL-C-5541)	CHEMICAL FILMS FOR ALUMINUM AND ALUMINUM ALLOYS
U. S. A. 72-53	(See AN-F-20)	FINISHES (FOR GROUND SIGNAL EQUIPMENT)
AXS-1245	(See JAN-C-490)	CLEANING AND PREPARATION OF FERROUS METAL SURFACES FOR ORGANIC PROTECTIVE COATINGS (EXCEPT FIXED INSTALLATIONS)

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whether there have been any books published recently on the subject.

—EDWARD HASSELL
Highland Park, N. J.

Ed—Regarding heat-resistant adhesives, we cannot give you any brand names on these materials. The adhesives described in our February issue were developed and are being used by General Motors.

However, you can obtain any infor-

(Continued on page 283)

mation you might want from either Mr. A. J. Kearfott or Mr. C. W. Roush, at the General Motors Research Laboratories in Detroit, Michi-

AMERICAN CHEMICAL PAINT COMPANY
AMBLER ACP PENNA.

Technical Service Data Sheet

ST PROOFING AND
HEMICALS

	SPECIFICATION TITLE
	PLATING, CADMIUM (ELECTRODEPOSITED)
	CANS, CORRUGATED: ASH AND GARBAGE, TAPER-SIDE, ZINC-COATED, WITH COVERS
	CHEMICAL FILMS FOR ALUMINUM AND ALUMINUM ALLOYS
NE"	COATINGS — PHOSPHATE; OILED, SLUSHED, OR WAXED (FOR FERROUS METAL SURFACES) AND PHOSPHATE TREATING COMPOUNDS
	EQUIPMENT, ELECTRIC POWER, BASIC REQUIREMENTS FOR (NAVAL SHIPBOARD USE)
	LINKS, METALLIC BELT, FOR SMALL ARMS AMMUNITION
	SURFACE TREATMENTS (EXCEPT PRIMING AND PAINTING) FOR METAL AND METAL PARTS IN AIRCRAFT
	VEHICLES, COMBAT, SELF-PROPELLED AND TOWED; GENERAL REQUIREMENTS FOR
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	TREATMENT AND PAINTING (FOR CONSTRUCTION AND ENGINEERING EQUIPMENT)
	ELECTRONIC EQUIPMENT; GENERAL SPECIFICATION FOR
NE"	FINISHES, FOR ELECTRONIC EQUIPMENT
NE"	FINISHES, PROTECTIVE, FOR IRON AND STEEL PARTS
NE"	PAINTING AND FINISHING OF FIRE CONTROL INSTRUMENTS, GENERAL SPECIFICATION FOR
	CONTAINERS, METAL, FOR ARTILLERY AND ROCKET AMMUNITION
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CHEMICALS ACP PROCESSES

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CHEMICALS ACP PROCESSES

1952 issue. —T. W. WHITE
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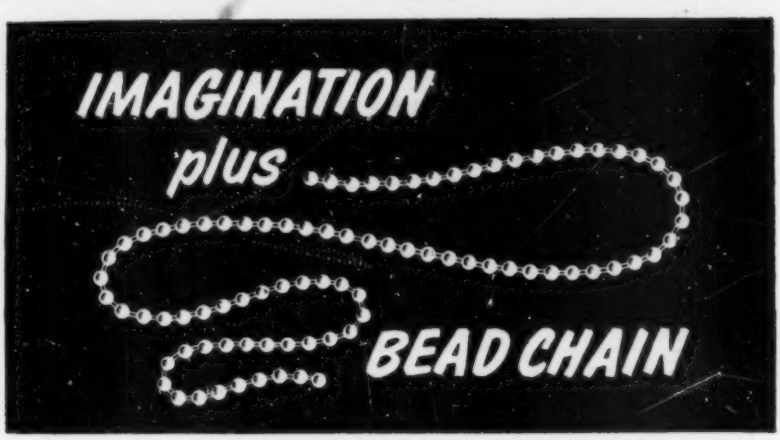

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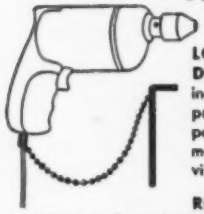

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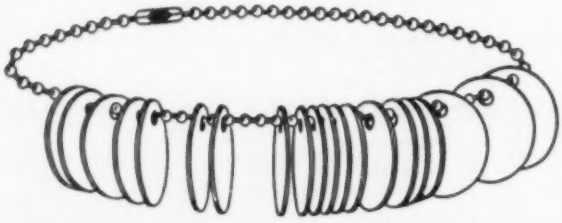

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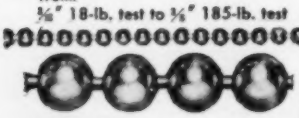

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tion Administration report, made in October 1950 by E. T. Morris, Jr., Chairman of the Electronics Production Board of DPA and Lt. Col. Carl B. Lindstrand of the Electronics Production Resources Agency. You may be able to obtain detailed information from this source.

Two manufacturers of selenium rectifiers were visited by the Government survey team. These are:

1. SAF (Suddeutsche Apparat Fabrik) Nürnberg, Germany
2. Siemens & Halske A. G., Munich, Germany

They manufacture conventional disk type rectifiers. Siemens & Halske has developed a rod type rectifier. This company could supply a half million rod type selenium rectifiers per year, the report states. They have an adequate raw material supply. You might try contacting these two companies directly.

High Pressure Lubricants

To the Editor:

We have noted with interest, on page 122 of your January issue, a brief reference made to the successful use of "Molybdenum Disulphide as a lubricant" where extreme bearing pressures are involved.

We would be much obliged if you could tell us where we could find a source for additional information relative to the use and procurement of this lubricant. —G. H. PIEL
Owens-Illinois Glass Co.

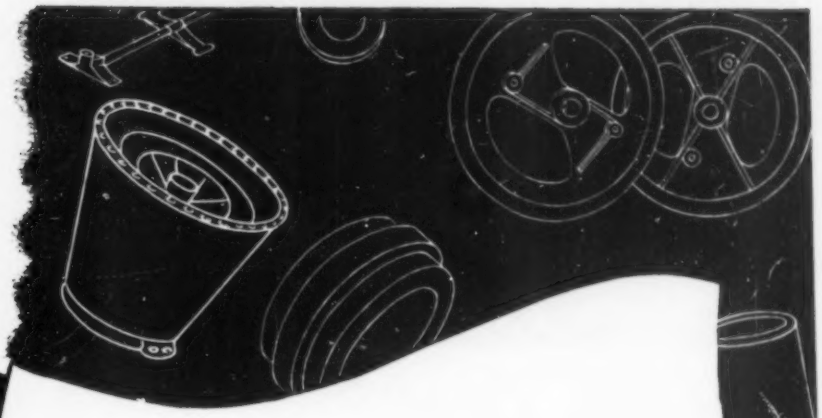
Ed—I suggest that you write to the Climax Molybdenum Co., 500 Fifth Ave., New York, N. Y. and request a copy of the booklet entitled "Molybdenum Disulphide as a Lubricant."

Where Are They?

To the Editor:

After reading the article appearing in the May issue of PRODUCT ENGINEERING regarding "Internal Drive Pumps", we directed an inquiry to Atlantic Pump Corporation, Philadelphia, Pennsylvania, which was returned due to insufficient address. We do not find this firm listed in Thomas' Register, and would very much appreciate receiving their mailing address from you.
—H. WESLEY SAVAGE
Oak Ridge National Lab.

Ed—The address of the Atlantic Pump Corp., mentioned on page 133 of the May issue is 4272 Wissahickon Ave., Philadelphia 32, Pennsylvania.



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Right—Entrance to offices of Fairfield's new plant in Lafayette, Indiana.
Above—Hobbing Spur Gear.

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NEW BOOKS

Numerical Methods in Engineering

MARIO G. SALVADORI, *Assoc. Prof. of Civil Eng., Columbia Univ.*; MELVIN L. BARON, *Research Assoc., Columbia Univ.* 258 *pp*, 6 x 9 *in. Published by Prentice-Hall, Inc., 70 Fifth Ave., New York* 11, *N. Y.* $6.65.

A well recognized shortcoming in the mathematical ability of many engineering graduates is the gap between the knowledge of the theories involved and the technique of applying these theories to physical problems. It is the purpose of this presentation, therefore, to introduce students, scientists, and particularly engineers to those elementary techniques which are needed more often in the solution of technical problems. It is assumed that the reader has a knowledge of the calculus and a smattering of differential equations.

The five chapters of the book deal with:

1. The solution of algebraic equations of high degree and of simultaneous linear algebraic equations.
2. The elementary theory of finite differences and its application to numerical differentiation, integration, interpolation, and extrapolation.
3. The solution of ordinary initial-value problems.
4. The solution of ordinary boundary and characteristic-value problems.
5. The solution of problems involving partial differential equations of boundary, characteristic, and mixed types.

In the presentation of the material, finite difference theory is made the unifying basis of all the numerical techniques. This makes the treatment of the various subjects efficient and avoids unnecessary repetition. It also allows a simple evaluation of errors throughout the book and, perhaps for the first time, the systematic use of efficient extrapolation procedures.

The various numerical techniques are either introduced by, or applied to, a simple illustrative problem taken from the various fields of engineering (mechanics, strength of materials, electricity, elasticity, plasticity, heat flow, vibrations, elastic stability, etc.) in order to give as wide a range of applications as possible within the limits of space and prerequisites. But the reader does not need to be familiar with the particular field of knowledge involved in the illustrative problem

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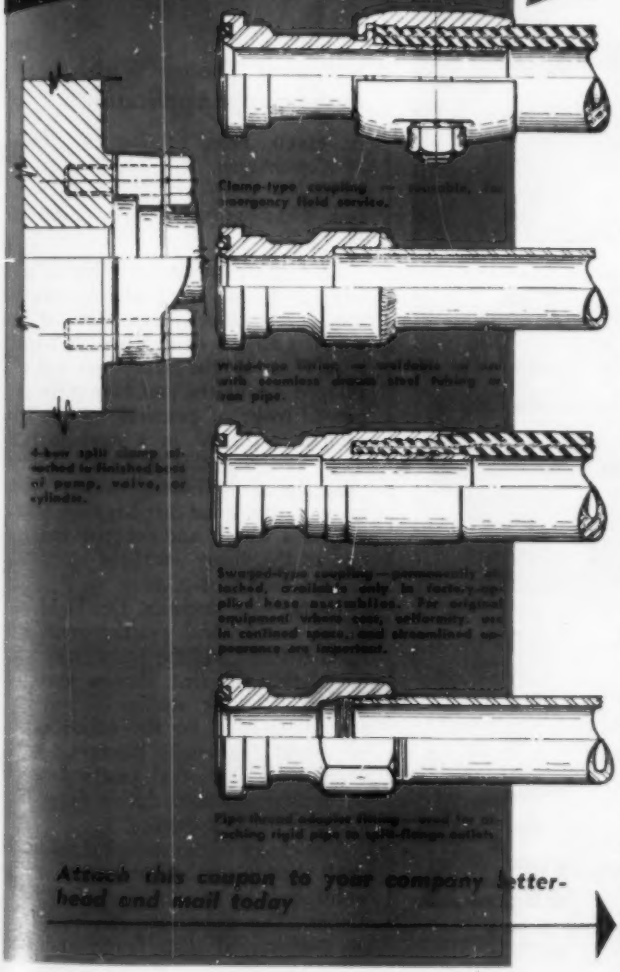

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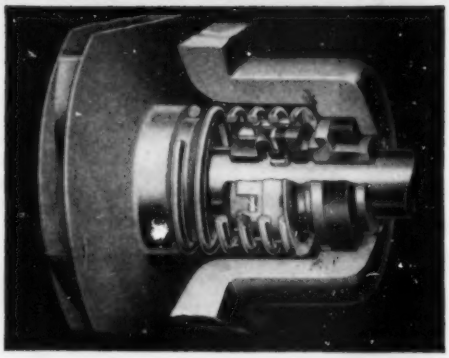

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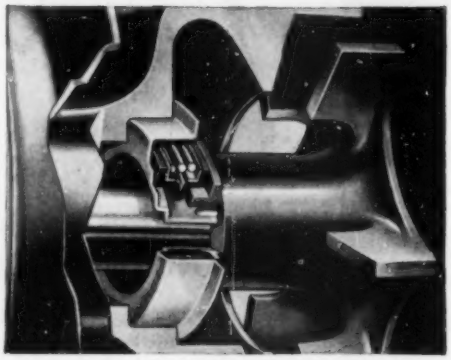

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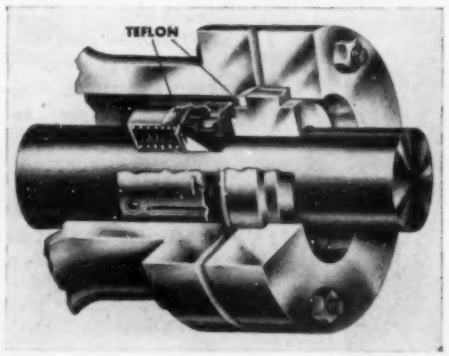

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to grasp the meaning of the numerical technique.

The choice of techniques was based upon their simplicity and efficiency: some have been known for over two centuries; others have been advanced in the recent past. The numerical tools to which these techniques can be applied are, usually, the electric desk calculator and, in many cases, the slide rule. Modern electronic calculators, to which most of these techniques can also obviously be applied, are not mentioned since their theory constitutes an entire new field of applied mathematics.

The problems at the end of each chapter are essentially of two types: purely numerical exercises and applied problems. Many of the numerical exercises represent actual physical problems and can be interpreted analogically in a variety of ways. The mathematical formulation of the applied problem is given or can be derived from the text or from the numerous references in the footnotes. Answers are given to alternate problems and to all problems whose answers are of general interest.

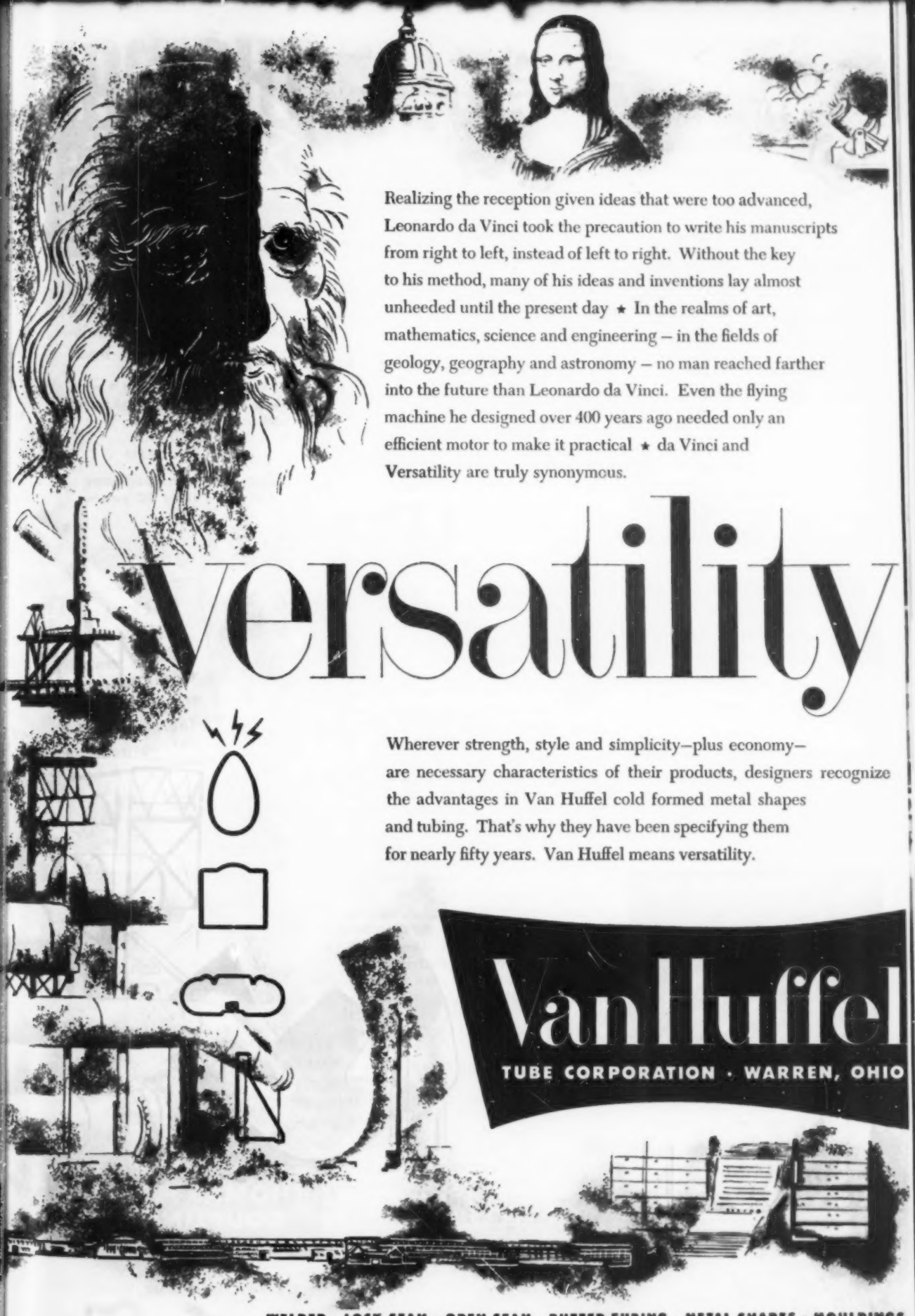
Statistical Theory With Engineering Applications

A. HALD, *Prof. of Statistics, Univ. of Copenhagen,* 783 *pp,* 7 x 10 *in. Published by John Wiley & Sons, Inc.,* 440 *Fourth Ave., New York* 16, *N. Y.* $9.

Using only standard differential and integral calculus this book presents the statistical methods important to the engineer in his daily work. It covers a large part of the theory that was developed during the past fifty years and proved to be of practical value. The subject is treated in a mathematical way, asserting that statistics cannot properly be understood in any other manner. But great care has been taken to give a simple and coherent exposition of the theory—without using advanced mathematics.

In studying statistics, Dr. Hald believes, theory and practice must go hand in hand, and the full significance of a theorem first dawns upon a reader when he studies a practical application of it. For this reason, every important theorem is illustrated with examples from actual practical work . . . most of them drawn from the author's own experience.

The choice of the statistical methods dealt with in the book has been much influenced by the works of R. A. Fisher. The main stress has been laid on the normal distribution and the



Realizing the reception given ideas that were too advanced, Leonardo da Vinci took the precaution to write his manuscripts from right to left, instead of left to right. Without the key to his method, many of his ideas and inventions lay almost unheeded until the present day ★ In the realms of art, mathematics, science and engineering – in the fields of geology, geography and astronomy – no man reached farther into the future than Leonardo da Vinci. Even the flying machine he designed over 400 years ago needed only an efficient motor to make it practical ★ da Vinci and Versatility are truly synonymous.

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tests of significance connected with this distribution, since these tests have proved to be of tremendous practical value.

Published in conjunction with this book is a separate volume that includes a comprehensive set of statistical formulas of practical importance and tables containing standard statistical functions. The latter section is designed so that interpolation is unnecessary; in this respect it is more useful than most other tables prevously published.

Electrical Reference

E. S. LINCOLN, *Consulting Engineer, Fellow, AIEE*, 8¼ x 11 *in.*, 1744 *pages. Published by the Electrical Modernization Bureau, Inc.*, 110 *Mamaroneck Ave., White Plains, N. Y.* $25.

This is the second edition of a reference book that proved to be of great practical value to plant electrical engineers, plant maintenance men, electrical contractors, design engineers, and other groups interested in industrial and commercial applications of electric power. The book covers all the practical aspects—description, ratings, operating principles and functions of all types of electrical equipment.

The data in the new edition have been carefully revised and expanded to include the latest information on equipment and uses. The information is clearly and simply presented by means of text, diagrams, charts and tables so that the book should be helpful not only because it shows how electrical equipment operates, but how to operate it, and where to get it.

The book is divided into twenty-six sections, designated as follows: Electrified Industry, Electrical Fundamentals, Industrial Wiring Systems, Switchboards and Substations, Panelboards, Electrical Control, Electrical Protective Equipment, Motors and Generators, Capacitors, Industrial Lamps and Lighting, Industrial Electrical Heating, Electrical Furnaces, Electric Welding, Signal and Communication Systems, Transformers, Primary and Storage Batteries, Industrial Electronic Equipment, Electrical Measuring Instruments, Electrical Measurements, Electrical Surveys, Electroplating and Electrolysis, Miscellaneous Electrical Equipment, Electrical Insulation, Maintenance of Electrical Equipment, Mechanical Drives, Cumulative Index, Table Index, NEC Index, NEMA Index.

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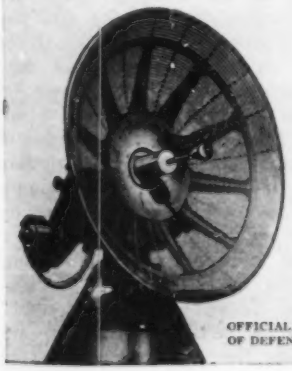

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the 1951 National Electrical Code, and the NEMA Standards is one of the features of the book. The entire Code is included, but the various articles are part of the particular section to which they apply. The index already referred to makes it easy to locate any article or section of an article. The same applies to the NEMA Standards both as to location and indexing.

Every effort has been made to insure the practical nature of the information, its authenticity and accessibility. As a result, the book should be a valuable addition to executives, operating or maintenance plant personnel, contractors and students.

Die-Casting—Second Edition

CHARLES O. HERB, 310 *pp*, 6 x 9 *in. Published by The Industrial Press*, 140-148 *Lafayette St., New York* 13, *N. Y.*, $4.50.

Die-casting from its early phases up to today's advanced practice is thoroughly covered in this second edition. The chapters relation to die-casting machines, die-casting alloys, and steels for dies and die components have been extensively revised. New examples of unusual die-castings have been added —including a detailed description of an induction motor rotor die-cast as a single unit around stacked laminations.

The latest models in automatic and manually operated die-casting machines are illustrated, such as fully hydraulic machines of the vertical cold-chamber and horizontal cold-chamber types, air-operated vertical machines, machines convertible from cold-chamber to gooseneck type operation, etc. An interesting adaptation of a vertical hydraulic press to die-casting work is also described.

Six new tables of die-casting alloy compositions and properties have been added to the chapter on alloys, and these are supplemented by the text discussion of their applications.

The chapter relating to steels for die-casting dies will be of particular interest to die designers since the tabular arrangement of the data presented is an aid in the selection of the proper type of die steel for each component of the die-casting die.

As in the previous edition, a distinctive feature is the large number of illustrations and detailed descriptions of dies for parts ranging from simple shapes to complex forms. The die designs which are illustrated are the work of die design specialists, and have been successfully used in industry. To further aid the designer, there is a section illustrating and describing the die design standards

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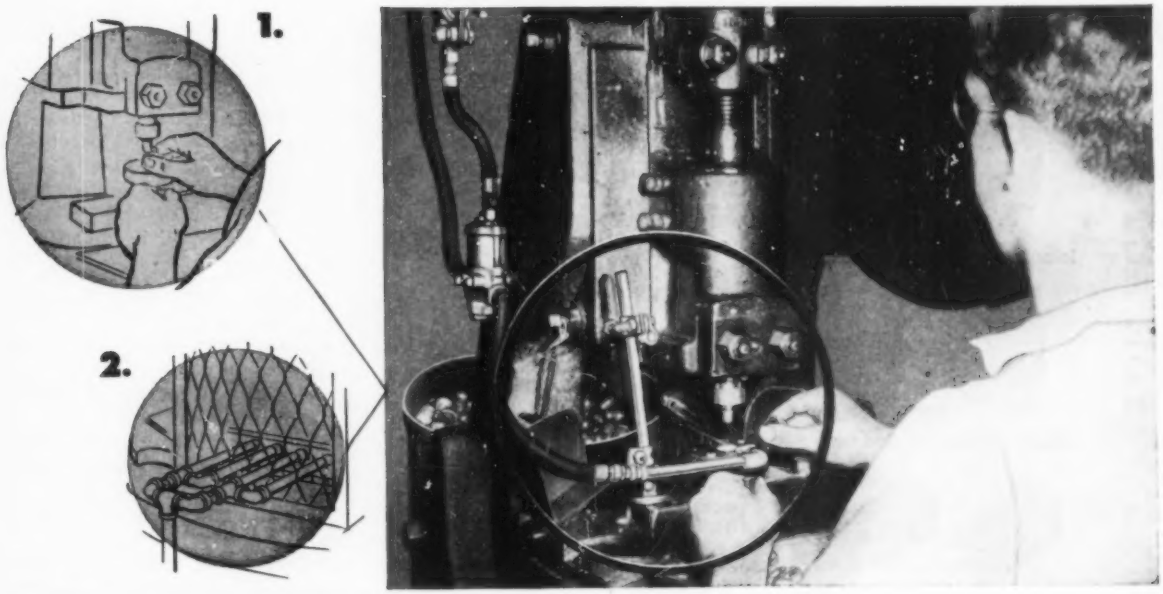

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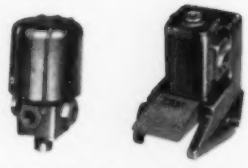

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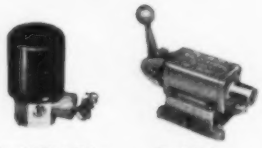

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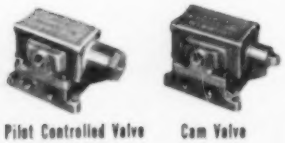

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Statistical Quality Control

EUGENE L. GRANT; *Professor of Economics of Engineering, Stanford University. Second Edition.* 557 *pages,* 6x9 *in. Published by the McGraw-Hill Book Co.,* 330 *West* 42*nd St., New York* 36, *N. Y.* $6.50.

Much expansion in the use of the techniques of statistical quality control has occurred since the first edition of this book was published in 1946. In hundreds of industrial companies, their use is now accepted as a routine and commonplace cost saving matter. Many of the statistical techniques originally developed for use in manufacturing can be applied successfully to clerical work and other manufacturing activities.

This second edition includes many important changes from the first edition.

The chapters dealing with acceptance samping by attributes have been expanded and largely rewritten to include developments in multiple and sequential sampling. Rewriting has been aimed at up-to-date coverage of the attributes sampling procedures used by the military services; the objective has also been to improve the presentation of fundamental principles.

The chapter dealing with acceptance sampling by variables has been entirely rewritten. Many recent developments in this field are described, including the Shainin Lot Plot and the variables tables and procedures developed by the Applied Mathematics

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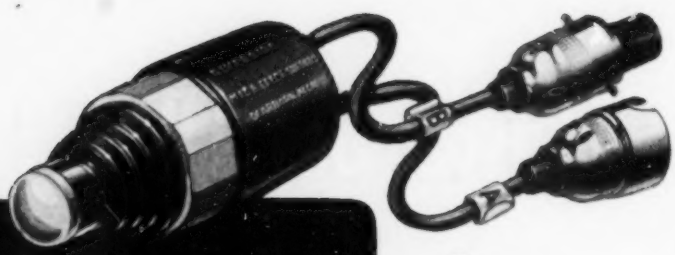

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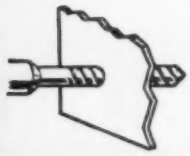

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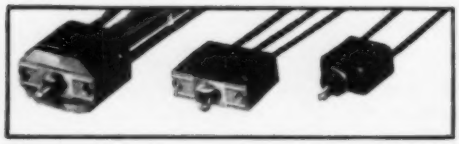

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and Statistics Laboratory of Stanford University.

The treatment of the cost aspects of quality decisions has been considerably expanded.

Master tables from "Military Standard 105A—Sampling Procedures and Tables for Inspection by Attributes" have been included in an appendix. Two tables for use in variables sampling are also included.

Like that of the first edition, the object is to present a book that might be useful to production and inspection supervisors, to engineers, and to management. The aim is to give just enough theory to supply practical working rules that will enable one to recognize the limitations of the methods as well as their many uses.

Management Controls in Industrial Research Organizations

ROBERT N. ANTHONY, *Associate Professor of Business Administration, Assisted by* JOHN S. DAY, *Research Associate, Division of Research, Graduate School of Business Administration, Harvard University,* 537 *pp,* 5½ x 8½ *in. Published by Division of Research, Harvard Business School, Soldiers Field, Boston* 63, *Massachusetts.* $6.75.

The growth of scientific research departments in American industry has given rise to numerous relatively new problems of administrative control. Scientific research necessarily is nonstandard and individualistic. The very circumstances, however, which render it difficult to exercise effective administrative control over scientific research activities also intensify the need for such control.

Business organizations have developed useful control techniques for production, finance, marketing, and other functional areas. The development of control techniques for the research function has not progressed so far. Dr. Anthony recognizes that research activity differs greatly from other activities of the industrial firm; that success in research largely depends on the freedom of the research worker. He contends, however, that industrial research must be managed as it is only one part of the activity of an organization with finite resources and specific over-all objectives. The conclusion is that the central problem in the management of industrial research is one of finding "the proper balance between freedom at the laboratory level and direction from the top."

The kinds of information on which the study is based consisted of (1)

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over 200 interviews with research administrators, controllers, financial executives, presidents of companies and their assistants, government officials, university faculty members, and consultants; (2) responses to a survey mailed to all the research organizations listed in the National Research Council Directory as employing more than 15 persons; and (3) literature primarily in the field of management control problems in research organizations.

Part I, *Statement of the Problem*, focuses on the particular aspects of research management to be included in the study. These are described as aspects of (1) the management of the technical program, (2) the management of service activities, (3) the management of money, (4) equipment management, and (5) personnel management.

In Part II, the reader's attention is directed to *Factors Which Relate to the Problem*. These variables are isolated and described under three general classifications: Factors common to control problems in general; the research worker and the research process; and factors responsible for differences among laboratories.

In Part III, the author treats current control practices within a functional classification as follows: Planning the technical program, budgeting by organization units, operation of and checking up on the technical program, operating control over certain types of spending, control of service departments, accounting for and checking up on spending, control of the procurement and use of equipment, yardsticks: comparisons with other laboratories.

Four chapters, describing in detail the current control techniques in four specific industrial laboratories, compose the concluding part of the study.

Primer of Electronics and Radiant Energy

DON CAVERLY, *Second Edition;* 6 x 9 *in;* 342 *pp. Published by McGraw-Hill Book Co., Inc.,* 330 *West* 42*d St., New York* 36, *N. Y.* $3.

With the many advances made in radio and television fields, and with the development and use of atomic energy to peacetime projects, there has been a desire for information about the electron and radiant energy. This book, containing general principles underlying electronics and how radiant energy is produced and controlled, is actually a digest of information on how electrons, protons,

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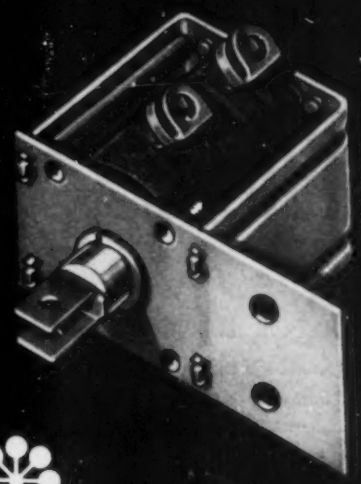

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Many specially prepared illustrations supplement the text.

Theory of Matrices

SAM PERLIS, *Associate Professor of Mathematics, Purdue University.* 237 *pp,* 6 x 9 *in. Published by Addison-Wesley Press, Inc., Cambridge* 42, *Mass.,* $5.50.

The theory of matrices is covered in such a manner that this book is suitable as a text for both mathematics majors taking a first course of one semester, and for other students of meager mathematical background. Care is taken in writing proofs, discussions, and examples to illustrate definitions and theorms. In addition there is a generous supply of exercises including adequate amounts of numerical work, but bearing on simple theoritical questions. Occasional queries are inserted in the text proper to focus attention on a fine point or to stimulate review of earlier topics. Where parallel theories occur, one is worked out in detail and the other merely outlined, details of proof being left for the student to work out.

The main purpose of the book is to establish the well-known canonical forms. Rank, nonsingularity, and inverses are introduced in connection with the development of canonical matrices under the relation of equivalence, and without the intervention of determinants. Congruence and Hermitian congruence are the next major topics. In the latter chapters, characteristic vectors and roots lead to the various diagonalization theories, culminating in the study of normal matrices.

Numerous supplementary topics are treated in appendixes located at the

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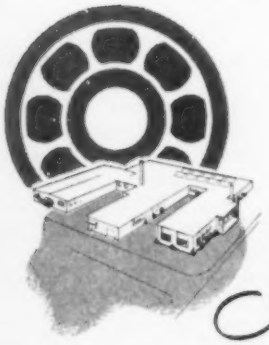

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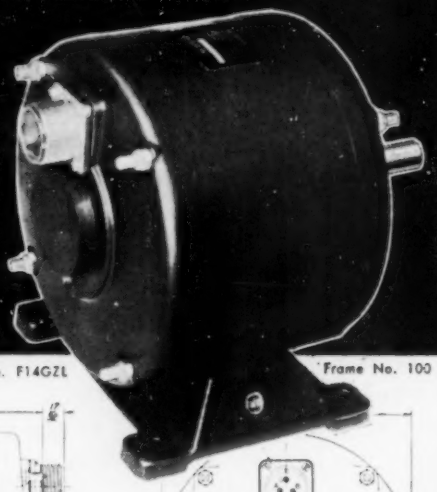
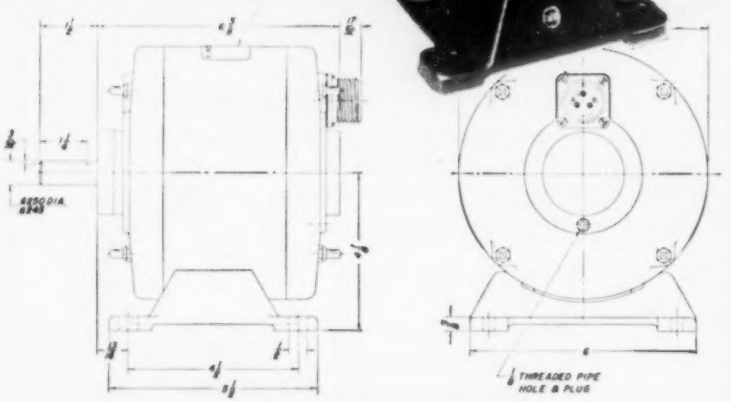


Model No. F14GZL Frame No. 100



A small fractional H.P. all-purpose electric motor completely waterproof and capable of instant operation even after long periods of submersion in sea water. Another example of EAD's engineering know-how!

SPECIFICATIONS

A.C. Single phase capacitor or 3 phase squirrel cage motor. Induction or synchronous • Reversible rotation • 115V or 220V • 60 or 400 cycles • 1/15 H.P. to 1/3 H.P. • 900 RPM to 12,000 RPM • Continuous or intermittent duty • Meets military specifications for corrosion resistance, fungus-proof, humidity, shock and vibration.

Motor can be furnished totally enclosed or open, with terminals or connectors as required. Can be mounted for operation in any position. Will function efficiently in ambient temperatures up to 71°C.

APPLICATIONS

Driving fans, blowers, pumps, generators and antennas.

Solving special problems is routine at EAD

If your problem involves rotating electrical equipment, bring it to EAD. Our completely staffed organization will modify one of our standard units or design and produce a special unit to meet your most exacting requirements.

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ends of various chapters. Thus they are available near the point at which they become relevant but are not intrusions upon the development of the main theorems.

The text is laid out so that it can be covered rapidly or slowly depending on the mathematical background of the student. For advanced mathematics students the text material can be covered in one semester, while a year should be devoted to it for students of engineering, psychology, chemistry, and other subjects.

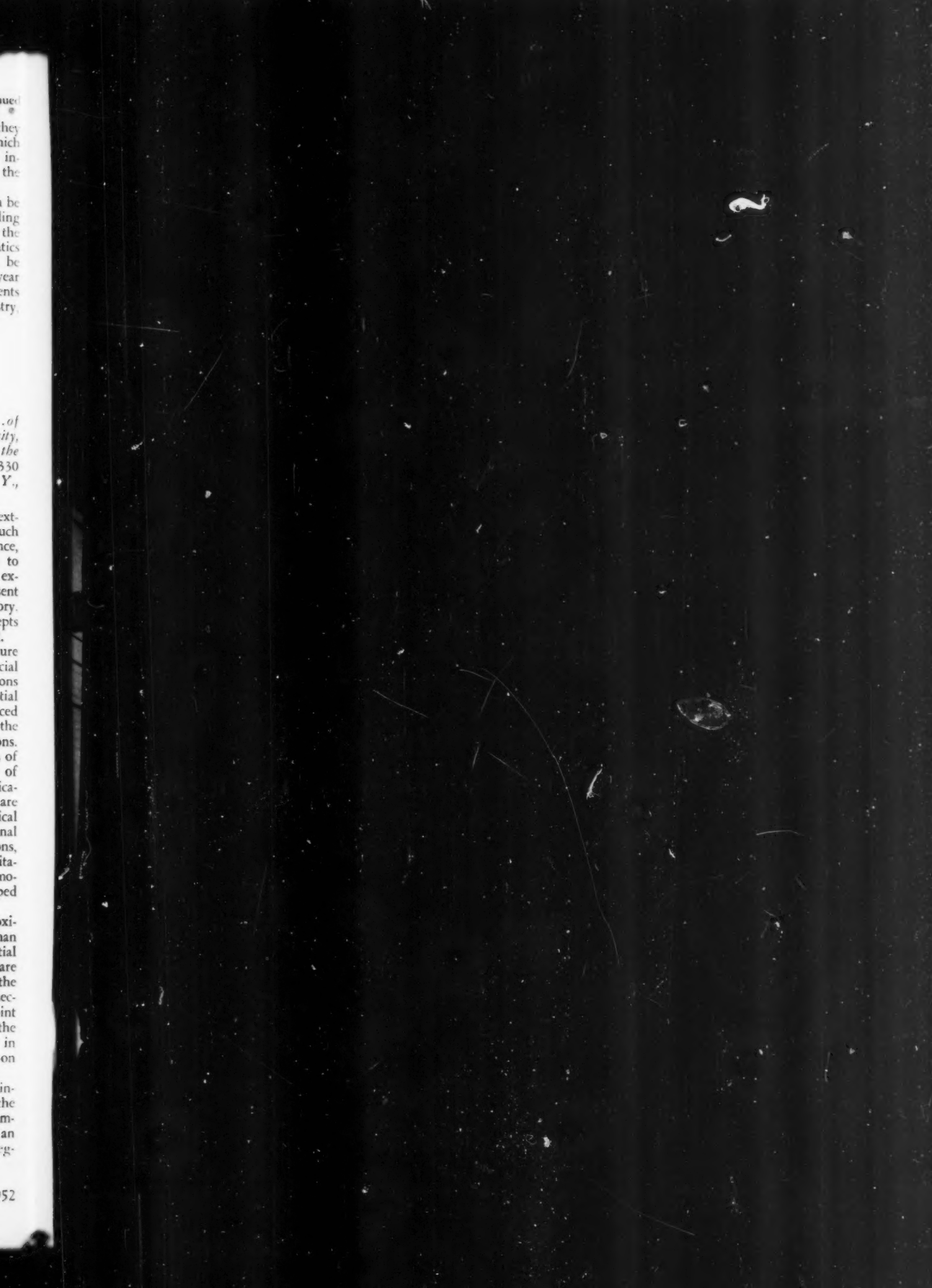
An Introduction to The Theory of Differential Equations

WALTER LEIGHTON, *Professor of Mathematics, Washington University, 174 pp, 6 x 9 in., Published by the McGraw-Hill Book Co., Inc., 330 West 42 St., New York 36, N. Y.,* $3.50.

In planning and writing this textbook, covering a subject of much theoretical and practical importance, an unusual effort has been made to give substance to the fundamental existence theorem and to present coherently the content of the theory. The aim being to make these concepts a part of the students background.

This book is a distinct departure from the usual collections of special methods of obtaining formal solutions of the various types of differential equations. The author is convinced that such collections impart to the student only a few superficial notions.

The more useful formal methods of solving differential equations, of course, are presented. The applications of the methods discussed are selected from the field of classical mechanics. These include orthogonal trajectories, mixtures, decompositions, Newton's laws of motion, gravitational attraction, simple harmonic motion, the vibrating spring, damped vibrations, and forced vibrations.

The method of successive approximations is given more attention than is usual in textbooks on differential equations. Particularly complete are the treatments of subjects such as the linear differential equation of the second order, the regular singular point in the real domain as discussed in the chapter dealing with solutions in power series, and the theorems on oscillation.

For reference appendices are included that deal rigorously with the fundamental existence theorem, implicit-function theorem, existence of an integrating factor, and regular integrals.